

THE
WONDER BOOK
OF
MAGNETISM



EDWIN J. HOUSTON

MC.

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AURORA BOREALIS

Showing the formation of the auroral curtain.

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THE WONDER BOOK OF MAGNETISM

BY
EDWIN J. HOUSTON, Ph. D.

Author of "The Wonder Book of Volcanoes and Earthquakes,"
"The Wonder Book of the Atmosphere."
"The Wonder Book of Light," etc.

WITH 77 ILLUSTRATIONS



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PREFACE

IN "The Wonder Book of Magnetism" an attempt has been made to present this difficult subject in a way that will not only permit young people to understand it but will even render it interesting.

For this reason fairy stories have been introduced wherever, in the judgment of the author, it seemed they would throw light on difficult subjects. An extended experience in teaching natural science to young people has convinced the author of the advisability of employing any reasonable kind of illustration that will throw additional light on some especially difficult point not likely otherwise to attract the reader's intelligent attention.

The subject of magnetic flux has been introduced by reference to the story of the invisible attendants in the palace of "The White Cat." The constant escape of magnetic flux from the north pole of a magnet, and its re-entrance into the magnet at its south pole, finds an illustration in the story of the "Blowing Servant of Fortunio." But it is especially in the story of the "Magic Wand" and "Unemptiable Purse of Fortunatus" that the almost magical ability of a magnetised penknife-blade continually to expend energy in magnetising other penknife-blades without losing any of its magnetising power, finds its best illustration.

Again, the close kinship of Oersted's and Faraday's

discoveries is emphasised by the heading, "The Great Twin Brothers."

The author desires to acknowledge the liberality of the publishers in the way of illustrations; for, in a book of this kind, it is by means of numerous pictures that the subjects can be best explained.

Acknowledgment is gratefully made to Messrs. William Wood and Company, Messrs. P. F. Collier and Son and The McGraw Publishing Company for permission to reproduce various illustrations in this volume, and to Messrs. Macmillan and Company, Ltd., for permission to use illustrations on pages 58, 60, 148, 192, 251 and 262, reproduced from "Guillemin's Electricity and Magnetism."

E. J. H.

PHILADELPHIA, 1908.

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CHAPTER I

THE INVISIBLE ATTENDANTS

IF I should ask you to tell me which of all the fairy stories you have ever read you consider the most wonderful, I think you would have no little trouble in deciding. There are so many wonderful fairy stories that you probably could not answer me offhand. Indeed, even after making a choice, you would probably wish to change it. If, as is not improbable, being unable to answer my question, you turn to me and insist that *I* name the story *I* consider the most wonderful, I think I could safely reply: "The Story of the White Cat."

It is possible that some of you have not read this story; or, if you have read it, have forgotten parts of it. Let me, therefore, briefly tell you the story and why I think it so wonderful. It runs as follows:

"Once upon a time there was a king who had three sons, all of whom were so clever and brave that he feared they would want to rule over the kingdom before he died.

"Now, although the king felt that he was growing old, yet he did not wish to give up the government for many years, for he was still able to manage it fairly well. He concluded, therefore, that the best way to keep peace would be to divert the minds of his sons by promises that he would surrender the government to them under certain conditions. So he sent for them, and, after speaking kindly, said:

“‘I am sure you will agree with me, my dear children, that my increasing age makes it impossible for me to look after the affairs of state as carefully as I once did. I begin to fear that this may affect the welfare of my subjects, and, therefore, wish that one of you should succeed to my crown. In return for such a gift, it is only right you should do something for me. Now, as I think of retiring into the country when I give up my throne, it has occurred to me that a beautiful, intelligent, little dog would be excellent company. Without, therefore, any regard to your ages, I promise that whoever brings me, one year from to-day, the most beautiful dog shall at once succeed me on the throne.’

“The three princes, of course, set out in search of a little dog such as the king had asked them to obtain. Each tried to get a dog so much more beautiful than any obtained by his brothers that the king would be compelled to give to him the throne; so during the year that had been given to them for this purpose, they travelled into different parts of the world, and collected many dogs, arranging their travels so as to return to their father at the end of the year.

“The youngest prince, like his brothers, bought dogs by the thousand. As soon as he obtained a new dog that was undoubtedly better than those he had already purchased, he gave the others away, since it was inconvenient in those days, even for a prince with plenty of money in his pockets, to travel from one country to another with so many dogs.

“Now the younger son was an exceedingly handsome prince, full of life and courage, and knew pretty much

everything that a prince ought to know. He journeyed from day to day without always knowing just where he was going, until one day, as the sun was setting, he reached a gloomy forest, in which he soon lost his way. To make matters worse, a violent thunder storm started and the rain began to fall in torrents. Taking the first path he could find, he followed it for a long time, until he thought he saw a faint light in the distance, and began to hope he was coming to some cottage where he could find shelter for the night.

“Guided by the light, he at length reached the door of one of the most beautiful castles he had ever seen, indeed, far more beautiful than any he had even imagined. Its door, made of solid gold covered with carbuncles, appeared to shine of itself with the red light that had attracted him when lost in the forest. The walls of the castle were of the finest porcelain, beautifully, though delicately, coloured. On them were all the stories the prince had ever read, told not only in words, but also in beautiful pictures. Since the prince was wet, and the rain was still falling in torrents, he only stopped a moment to look at the pictures and then came back to the golden door. There he saw a deer’s foot hanging by a chain of diamonds, and began to wonder who could live in such a magnificent castle.

“Pulling the deer’s foot, a silver bell immediately sounded and the door flew open.”

Now it was what the prince saw that makes this story more wonderful than any other fairy story I remember reading.

“A number of flaming torches appeared, each held

in a hand resting in the air, but there was nobody attached to the hands of the invisible attendants. The prince was so surprised that he stood quite still at the open door, making no attempt to enter the castle. But he soon felt himself gently pushed forward by the hands, so that, although somewhat uneasy, he could not help entering and walking through a hall paved with blocks of lapis-lazuli. Here he heard the kindly voices of invisible beings who assured him that the hands he saw floating in the air would obey all his commands; that he need not fear to enter and remain in the castle since he would be kindly treated and well cared for.

“Assured by these voices and guided by the mysterious hands, he was led, or, more correctly, gently pushed towards a door formed of pink coral, that opened of itself as he approached it. Passing through this door he found himself in a vast hall of mother-of-pearl, from which many doors opened into rooms in each of which thousands of lights glittered, and all of which were filled with so many beautiful pictures and precious things that he felt quite bewildered. Entering one of these doors, he was guided through room after room. It was not until he had thus passed through sixty separate rooms, each more beautiful than the preceding, that the hands conducting him stopped, and the prince saw a comfortable-looking arm-chair drawn close to a chimney-corner.

“As soon as the prince sat down in the chair, a fire lighted itself on the hearth, and soft, white hands removed his wet, muddy clothes, and gave him new, dry clothes made of richer stuff and embroidered with gold and emeralds. He could not help admiring everything he saw,

especially the clever way in which the hands waited on him.

“The prince afterwards discovered that he was in the palace of a beautiful princess who had been changed by a fairy into a white cat. He spent all the time that remained of the year given him by his father to obtain the most beautiful dog in the world, with the white cat, with whom he fell in love; for, although she had the form of a cat, yet she could converse as well and indeed even better than the prince himself. At last the white cat reminded the prince that he had but a short time left in which to return to his father, and presented him with a small English walnut. Then, giving him a magnificent retinue, she transported him by magic to his father’s court. The walnut, when broken, was found to contain a dog far more beautiful than any his brothers had obtained.

“Still unwilling to give up his throne, the king made excuses for not keeping his promise, and sent the three princes off again for another year on a search, this time for a piece of muslin so fine that it would easily go through the eye of a needle.”

I will not stop now to tell you how, after passing this year with the white cat, the prince returned to his father’s court bearing in his hand a hazel-nut. Showing this to the king, he cracked it, confidently expecting to find the piece of muslin within it; but, instead of that, it only contained a cherry stone. Cracking the cherry stone he found nothing in it except the kernel, and opening this he found a small grain of wheat inside of which was a millet seed. Fearing he had been fooled he began to mutter softly to himself:

“ ‘ White Cat, White Cat, are you making fun of me ? ’

“ Then he immediately felt a cat’s claws give his hand a sharp scratch ; so, opening the millet seed, he drew out of it a piece of muslin 400 ells in length, woven with lovely colours in a wonderful pattern, and when the needle was brought, the muslin passed through its eye six times with the greatest ease.

“ Still unwilling to give up his crown, the king again sent his three sons to search during another year for a beautiful princess, promising this time faithfully that the son who brought the loveliest princess back with him should immediately marry her and ascend the throne.

“ It is enough to say that the younger prince spent another year in the palace of the white cat, freed her from the enchantment, and returned with her to his father. The king awarded the prize to his youngest son, but the princess informed the king that she had six kingdoms herself ; that, therefore, she would give the king one of these kingdoms and bestow a kingdom on each of the other sons. So the prince and the princess were married and lived happily together ever afterwards.”

Of course, the wonderful thing about this story was the invisible attendants, who did so much to ensure the prince’s comfort. Their hands only were visible. The people to whom the hands belonged were absolutely invisible. I can readily imagine how greatly surprised the prince must have been, when, merely wishing to have something done, without even whispering it, a pair of hands would instantly appear out of the air around him, and, having done what he wished, would as suddenly disappear.

Just think of it. Suppose, while you were quite alone in a room where you were sure there was no one besides

yourself, you wished for something that was in another part of the room. A pair of hands suddenly appear floating through the air and instantly bring you the article you wanted. Or suppose you were fifty or a hundred miles from your home, paying a visit in another city, and, discovering that you had left something you especially wished to bring with you, had exclaimed :

“How stupid I was not to have brought it. I wish I had it here.”

Would it not surprise you if, suddenly, the door opened of itself and a pair of hands came floating through the air, directly towards you, bringing the very thing you wished you had, and this, too, in less than a minute from the time you had wished for it, although the place in which you had left it was so far away?

Of course, I acknowledge there are many other fairy stories that might, perhaps, be regarded by some as equaling in wonder the story of “The White Cat”; for, as everyone knows, fairy stories appear to have been made purposely to tell what seemed at the time to be exceedingly improbable, if not, indeed, impossible. There is, therefore, to be found in practically every fairy story, something that might, perhaps, be regarded as wonderful as anything in the above story. Still there is something about the invisible attendants that so closely resembles some of the wonders of magnetism I am about to describe, that I have purposely selected this story as an excellent introduction to this Wonder Book.

I imagine I hear someone exclaim how ridiculous it is in this age of progress to introduce so important and interesting a subject as magnetism by such an improbable and ridiculous a thing as a fairy story. Now I wish to

say that I do not at all agree with the assertion that fairy stories are necessarily either improbable or ridiculous. I believe I have read nearly all the fairy stories that have ever been printed in the English language, and, indeed, in many other languages, and I can say that, selecting from these the old, old fairy stories that have been handed down from one generation to another, from the times of our great-great-great-grandfathers and grandmothers, or even earlier, to the present time, I am very far from believing these stories either improbable or ridiculous. On the contrary, I find that it is possible to interpret them in ways that will enable one to find in them the germs of some of those great principles of natural science it has been the pride and glory of these latter years to discover. I do not say that the stories have intentionally included the germs of these great truths. I do not attempt to explain it at all. I simply say that I find these truths in nearly all such stories.

In this first chapter of *The Wonder Book of Magnetism*, I wish to say that the science of magnetism is capable of calling to its aid hosts of invisible attendants far more powerful and intelligent than any of those that came not only at the audible call of the prince, but even appeared on those occasions when, instead of asking for something to be done, he merely wished to have such service performed. There are so many wonderful things that magnetism is able to do, by means of its invisible attendants, that I am sure this brief introduction of the fairy story of the white cat cannot fail to impress on your minds, far better than I could do in any other way, the fact that magnetism, too, has its invisible attendants.

CHAPTER II

THE INVISIBLE AND MYSTERIOUS FORCE OF MAGNETISM

I HAVE often been greatly amused by hearing men declare that all women are naturally and hopelessly curious. Now, if the truth were known, generally speaking, women are far less curious than men, especially if the men happen to be scientifically inclined. This is true, not only in the objectionable sense of the word curiosity, as an inquisitiveness that leads one to look or pry unnecessarily into the affairs of others, but also in its more correct sense of a disposition to seek for information or knowledge of anything of interest. I am glad to say that scientific men are as apt to be curious in this second sense quite as much as women. Indeed, I believe far more so; but I regret that, in fairness, I must acknowledge that, in the sense of prying unnecessarily into the affairs of others, men, and often even scientific men, are perhaps more curious than women.

The history of physical science contains many cases of men who have been so curious or anxious to discover the causes of natural phenomena that they have pertinaciously continued to pry into the secrets of good Dame Nature for years and years until at last their efforts are rewarded by some grand discovery. This good-natured old woman, so far from resenting this kind of curiosity as impertinent, is always pleased to disclose her secrets to all who persist in intelligently questioning her.

I am particular in speaking of this kind of curiosity, because I am especially desirous you should feel that, when properly directed, curiosity, so far from being something to be ashamed of, is, on the contrary, something of which everyone has a right to be proud. I hope, therefore, when you are reading *The Wonder Book of Magnetism*, as well, indeed, as any of the other *Wonder Books*, you will permit your curiosity to be aroused to as great an extent as possible, and will continue being curious until you have learned all you can.

I am glad to say that we shall find in the force of magnetism so much that is both mysterious and wonderful that I trust, while reading *The Wonder Book of Magnetism*, your curiosity will be aroused again and again, and that you will encourage it to be aroused, for I am sure in this way you will be able to learn no little.

What especially tends to make the force of magnetism wonderful is that it is absolutely invisible. We can, perhaps, the better understand its mysterious properties if we take some of them up, one by one. Suppose, to begin with, we take one of the commonest phenomena of magnetism; *i. e.*, that of the magnetic needle in the mariner's compass. I do not mean that we will now attempt to explain the many curious and interesting things that have been discovered concerning this wonderful and yet exceedingly simple piece of apparatus. This we shall do in a subsequent chapter, after some of the general principles of magnetism have been more fully described. We will limit the discussion here to the power the compass needle possesses of pointing approximately to the earth's north in no matter what part of the earth it may happen to be placed.

It is a mistake to suppose that because a phenomenon occurs frequently it, therefore, ceases to be wonderful. Of course, I acknowledge that it thereby ceases to be uncommon, and so cannot properly be called unusual, but it certainly should not cease to excite one's admiration simply because it is constantly occurring. On the contrary, it seems to me the very fact that it is happening again and again should rather cause it to continue to excite our admiration, especially if the causes that produce it continue to escape detection. Now the magnetic needle, or compass needle, presents natural phenomena that are certainly very wonderful in character.

But before saying anything more about the compass needle, let me first be sure you understand exactly what a compass needle is. I suppose all of you have seen a pocket compass. This extremely simple apparatus consists of a small piece of hardened steel that has been magnetised, and so supported at its centre on a vertical point that it is able to turn around easily in a horizontal position. When the box or case containing such a needle has been placed on a flat or horizontal surface, the needle, after moving a few times to-and-fro on its support, will come to rest with one of its ends pointing, approximately, to the north pole of the earth, and, of course, with its opposite end pointing towards the earth's south pole.

Provided there are no disturbing influences in its neighbourhood, the compass needle will always point in this direction. It does not need the light of the sun or of any other luminous source to enable it to find in what direction the earth's north lies so as to be able to point towards it. It can do this just as well at night, when there

is absolutely no light, as during the brightest daylight. Nor does it make any difference how far the needle may be from the earth's north pole. It may be within a few miles of the pole, or it may be as far from it as possible; that is, somewhere on the equator. After swinging to-and-fro for a few moments it will at last invariably come to rest with one of its ends pointing in this general direction. Moreover, it will do this at any season of the year, on any day of the week, or at any hour of the day or night. There is some mysterious or invisible force existing both at the end of the magnetic needle itself, as well as in the neighbourhood of the earth's poles, and, indeed, for that matter, as well also in the space between the end of the compass needle and the earth's poles, that endues the needle with its wonderful directive power, thus enabling it, when left to itself and free to move, never to fail to come to rest pointing towards the earth's north.

Is it, therefore, at all astonishing that the strange and mysterious force which is thus able to guide the compass needle should excite the curiosity and wonderment of all who witness its power? You will remember how astonished the prince was, while standing before the open door of the palace of "The White Cat," to be gently pushed by the hands of the invisible attendants into the hall, and through the successive rooms until he came to rest in the comfortable chair by the hearth. Does not the compass needle remind you in this respect of the prince, since it is gently pushed to-and-fro by the invisible attendants of the magnetic force until it comes to rest only when pointing approximately to the earth's north?

Now I suppose almost everybody knows that a magnetic

needle consists merely of a straight bar of hardened steel that has been endowed with magnetism in a number of ways we shall afterwards carefully describe, but which, in the case of a compass needle, generally consists in simply touching it with another bar that has already been magnetised. This mere touch is sufficient to endow the bar of hardened steel with the mysterious power of reaching out through thousands of miles until it finds unerringly the direction of the north pole of the earth.

There is always a dangerous tendency in the case of natural phenomena that have perhaps ceased to excite wonder because they occur so often, to accept unsatisfactory explanations as to their causes. This is especially apt to be the case with the compass needle. One sometimes hears people explaining the cause of the compass needle pointing to the north as due to the action of the magnetic force. Such people have so little curiosity that they are satisfied with the statement that it is natural for magnets to do this, forgetting that this is begging the question, and is practically the same as saying that a magnet acts in this way because it is its nature to do so. Of course this is no explanation whatever.

I certainly trust that none of my young readers will permit their curiosity to be satisfied with any explanation of this character until at least they have carefully considered how wonderful and mysterious a thing it is for a small piece of hardened, magnetised steel to be able to point unerringly to the earth's north. Think of it for a few minutes. The compass needle, we will say, is near the equator, at a distance measured over the earth's surface of, roughly, 6,250 miles from the earth's north pole, and

yet, through all this distance that tiny piece of hardened steel is able, after swinging to-and-fro for a few moments, to come to rest steadfastly pointing towards the north. If it happens to be a ship's compass needle, on the great ocean of water, it is nevertheless able to point to the north, even though huge mountain masses tower high above the level of the water between the needle and the earth's pole. It is certainly wonderful and mysterious in the extreme that the invisible attendants of the magnetic force are able, as it were, to see through the mountains and never fail to push the needle gently until it comes to rest in an approximately true north and south direction.

It is quite natural, therefore, that from the earliest times the strange and mysterious force of magnetism has never failed to excite curiosity in all kinds of people, not only

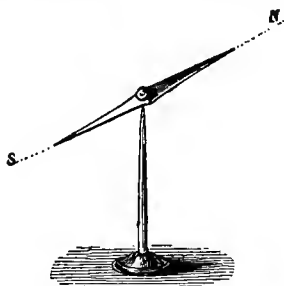


FIG. 1.—A COMPASS NEEDLE

in the uneducated, who are apt to wonder at even ordinary natural phenomena, but also among the most highly educated, who have spent almost all their lives prying into the secrets of nature in order to discover, if possible, the causes of these wonderful things.

But it is not only, approximately, to the north pole of

the earth that one end of the compass needle points. It will also point towards other magnets, especially towards the ends of other compass needles. If a compass needle be placed on the end of a vertical support, such as represented in Fig. 1, it will point to the earth's north, provided there is nothing in the neighbourhood to disturb it. Let us now, without stopping to explain what is meant by the word pole, call the ends of the compass needle its poles; naming the end which points towards the north pole of the earth its north pole, and the opposite end, its south pole; and that we mark these ends as represented in Fig. 1 by the letters N and S. If now another magnet, such as a magnetised bar of steel, be held in the hand and brought into the neighbourhood of the north pole of the needle, so that its south pole is brought near the compass needle's north pole, then the compass needle, instead of pointing towards the north pole of the earth, will point towards the south pole of the approached magnet, so that it comes to rest when pointing directly towards it, and, indeed, will follow the disturbing magnet, always pointing towards its south pole. Instead, therefore, of pointing towards the north pole of the earth it may come to rest pointing towards the approached magnet in a direction that may be due east, due south, due west, or in any intermediate direction.

Now that we have the ends or poles of the two magnets that are thus acting on each other in this curious manner near together, there is an opportunity for carefully examining their neighbourhood to see if, perchance, we cannot detect something reaching out between them that is capable of causing these motions. I may as well tell you here that the eye is unable to see any such force or

connecting lines. The space between the magnets as far as we can see is absolutely empty. Magnetism is, indeed, a mysterious force that is thus seemingly capable of acting at a distance.

If an attempt be made to shield or protect the end of a compass needle from the magnet pole by holding a plate of window glass directly between the two magnets, a wonderful fact will be discovered; the poles of the compass needle and the other magnet are able to influence each other almost as readily through the plate of glass as through the air, and this even if the glass plate possesses a fair thickness. Moreover, there are a variety of substances that, like glass, can be brought between the compass needle and the approached magnet, without, to any great extent, affecting the influence they exert on each other.

Nor is it necessary that the substances brought between the magnet poles be transparent to light like a plate of glass. The mysterious force that comes out of the poles of a magnet can also pass through such opaque substances as sheets of black paper, plates of coloured porcelain, or sheets of black rubber or vulcanite. Even the human hand can be held between the two magnets without greatly influencing the action they exert on each other.

There is a very simple experiment which illustrates the same principle. As you all know, a magnet possesses the power of attracting or drawing to its poles small pieces of iron or steel. If, therefore, the pole of a compass needle be touched to a mass of iron filings, some of the filings will cling to its ends with sufficient force, in case of a fairly strong magnetic needle, to make it somewhat difficult to wipe them all off. In the same way the ends of a compass

needle will draw towards it and hold pins and needles, so that if a sheet of glass be supported a short distance above the surface of a table on which a small quantity of iron filings, or a number of pins and needles, have been placed and the pole of the compass needle be placed against the upper surface of the glass plate, it will cause the objects to be drawn from the table and to cling to its lower surface. Moreover, if the compass needle be drawn slowly over the upper surface of the plate, the iron filings, or pins and needles, will follow the needle in an amusing manner. Here, as is evident, the mysterious force of magnetism readily passes through the glass plate.

It is well to note that iron pins only can be used for the purpose. Brass pins, now very common, will not answer, since brass is not as readily influenced by magnetism as is iron.

But besides the above instances of magnet poles acting on each other across the apparently empty space between them, there are numerous instances of similar attraction. In some of these the strength of the attracting force is very great, so great, indeed, as to be able to lift heavy weights and to move large bodies up steep hills. As we shall subsequently see, magnets can easily be made so strong as to be able readily to lift masses of iron or steel tons in weight and to hold on firmly to them while they are being moved from one part of a yard, or from one part of the floor of a workshop to another part.

I trust that in all these cases, you will not forget that the mysterious force of magnetism has remained absolutely invisible. Its attendants have completed the work assigned them and have remained as unseen as were the attendants to whom the hands of the people belonged who did so

many curious things for the Prince in the palace of "The White Cat."

Perhaps one of the most wonderful instances of the work of the invisible attendants of magnetism is to be found in the trolley cars. As you know, in any large city, and, indeed, in many country towns, you can every day see cars so heavily laden, that, were they drawn by horses, a team of fifty or more might have difficulty in starting them. Nevertheless, such cars, often so crowded that it is almost impossible either to get on or to get out, are capable, when the motorman turns the handle of the car controller, not only of almost instantly starting, but of acquiring a speed which would make it foolish for one to attempt to leave the car until it comes to a dead stop. It seems all the same whether the tracks are on a dead level or on a steep incline. The motorman turns the switch a little further in the direction of starting, and the car is almost as rapidly carried up a steep hill as it would be on a dead level.

One naturally inquires what it is that thus drags the loaded trolley car. I am sorry to say that ordinary people who are not curious enough are satisfied when they are informed that the cars are moved by electric motors; or possibly the information may be somewhat more correctly given, and they are told that the cars are moved by electromagnetic motors. In other words, it is the force of magnetism with its mysterious invisible attendants who are grasping the cars from beneath and rapidly moving their wheels despite the heavy weight with which they are loaded.

When the trolley cars were first introduced, and before they became so common as to cease to attract attention, the question was asked by intelligent people, who were properly curious in their endeavours to find out the nature

of the mysterious force that could do such work, "what is it that makes the cars move?" Among these were many youngsters who vainly endeavoured to get explained to them just what it was that made the cars move. I can imagine the following conversation as taking place between an intelligent lad and his insufficiently informed father:

"Father, what makes the trolley car move?"

"The electricity that runs from the trolley wire and through the tracks to the street, my son," replied the father wisely.

"But how does the electricity move the car, father?"

"By electric motors that are placed under the floor of the cars. The motorman turns the handle of the switch in the car controller and the electricity flowing through the motors between the trolley wire and the track causes the motors to move and in this way hauls the car through the streets."

"But how does the electricity make the motors turn?"

Now this question, capable of simple answer, possibly remained unanswered because the father was lazy or ignorant, so that the only satisfaction the boy received was:

"Don't ask so many foolish questions. I have explained to you several times what makes the car go, and if you are too stupid to understand it, I cannot take the time to bother any further with you."

The boy's search for information is thus summarily stopped, and his natural curiosity quenched, though, I sincerely hope, only temporarily.

That very clever and bright writer, Dr. Oliver Wendell Holmes, gives, in masterly and witty verse, a description of what he humorously says is the true cause that makes the trolley cars go. Of course you will understand that

Dr. Holmes is not in earnest about this, and is only giving it as a quaint conceit or fancy.

As most of you know, Dr. Holmes lived in the good old city of Boston, where people, notwithstanding their great wisdom at the present day, were foolish enough in the early days to believe that it was possible for very old women to ride through the air on broomsticks. I am not sure, but does it not seem possible, that the remote ancestor of these old women was the original old woman of the nursery books who declared she rode through the air on a broomstick, not with any mischievous intent, but **only** to sweep the cobwebs from the sky?

Now whether what the original old woman said was true or not, yet at the time referred to by Dr. Holmes it was alleged that these old women were by no means incapable of mischief; that they had entered into an unholy pact with Satan, and that each of them was invariably accompanied in her flights through the air on her broomstick by a black cat mounted on her shoulder.

Having thus given you an introduction to the story, I will let Dr. Holmes tell the rest himself by quoting from some of his verses. The poem is called "The Broomstick Train; or the Return of the Witches."

"Look out! Look out, Boys! Clear the track!
The witches are here! They've all come back!
They hanged them on high—No use! No use!
What cares a witch for a hangman's noose?
They buried them deep, but they wouldn't lie still,
For cats and witches are hard to kill;
They swore they shouldn't and wouldn't die,—
Books said they did, but they lie! they lie!"

Dr. Holmes then describes how the witches, having been given over to Satan as punishment for their wicked lives, feeling homesick, obtained permission to take their broomsticks and black cats for a short visit to the towns in which they had lived while on earth.

They found their broomsticks all right, but during the few hundred years they had been stored away, they had increased somewhat in length. But this did not worry them; so, calling their black cats and sitting astride their lengthened broomsticks, they flew through the air and thus visited the scenes of their childhood, where, I'm sorry to say, they played all sorts of pranks with the people and their belongings.

As Dr. Holmes correctly describes, there were many witches, and since each witch owned her own cat, there were necessarily many cats. But I will let him describe this in verse:

“ ‘ And where is my cat? ’ a vixen squalled.
‘ Yes, and where are our cats? ’ the witches bawled,
And began to call them all by name:
As fast as they called the cats, they came:
There was bob-tailed Tommy and long-tailed Tim,
And wall-eyed Jacky and green-eyed Jim,
And splay-foot Benny and slim-legged Beau,
And Skinny and Squally and Jerry and Joe,
And many others that came to call,—
It would take too long to count them all.
All black—one could hardly tell which was which,
But every one knew his own witch;
And she knew hers, and hers knew her,—
Ah, didn’t they curl their tails and purr!

No sooner the withered hags were free
 Than out they swarmed for a midnight spree;
 I couldn't tell all they did in rhymes,
 But the Essex peoples had awful times.
 The Swampscot fishermen still relate
 How a strange set monster stole their bait."

The Doctor now relates how the horses of an old horse-car, laden with people, were having so much difficulty in moving the heavy load that their strength was greatly taxed. Satan, who had come to earth to tell the witches that their holiday was over, as a punishment for the pranks they had been playing, told them that hereafter they must take the place of the horses and pull the street cars. They could have their broomsticks and their cats, he said, but henceforth they would be obliged to pull those trolley cars. I do not know whether Dr. Holmes had been troubled by the eager questioning of a too-bright grandson, as to what it was that made the trolley cars go. Indeed, for all I know, he may have written this poem as a good answer for such questionings, but at any rate he declares that the witches, sitting astride their long broomsticks, on the top of a trolley car, each with a black cat on her shoulder, are the real power that drives the car. You couldn't see the witch and you couldn't see her cat, but you could now and then catch a gleam of the witch's wicked eye and could even hear the black cat purr as the car rushed by.

* * * * *

"Since then on many a car you'll see
 A broomstick as plain as plain can be;

On every stick there's a witch astride,—
The string you see to her leg is tied.
She will do a mischief if she can,
But the string is held by a careful man,
And whenever the evil-minded witch
Would cut some caper he gives a twitch.
As for the hag, you can't see her,
But hark! You can hear her black cat's purr,
And now and then as a car goes by,
You may catch a gleam of her wicked eye.
Often you've looked on a rushing train,
But just what moved it was not plain.
It couldn't be those wires above,
For they could neither push nor shove;
Where was the motor that made it go
You couldn't guess, *but now you know.*"

CHAPTER III

WHAT THE ANCIENTS KNEW ABOUT MAGNETISM

MAGNETISM can fairly lay claim to be, if not the oldest, at least among the oldest of the physical sciences. The world has had some knowledge of its strange properties from exceedingly early times. Nor is this surprising, for the mysterious powers of its invisible attendants could hardly have failed to attract the attention of the thoughtful. But although magnetism can thus lay claim to great antiquity, and has, therefore, been carefully studied by able philosophers from early times, yet the principles of this peculiar force have by no means been thoroughly mastered. There still remains so much yet to be discovered, that, in some respects, the exact nature of magnetism is no more accurately known than it was many generations ago.

While we are ignorant as to just when and how the force of magnetism was first observed, there can be but little doubt as to the kind of matter in which it was first detected. It was in a common variety of iron ore known as lodestone, the peculiarities of which we shall discuss in a subsequent chapter.

Many of the specimens of lodestone that are found in different parts of the world are natural magnets, and possess both the power of attracting or drawing pieces of iron towards them as well as, when properly supported like compass needles, of pointing approximately to the earth's north.

The name of the individual to whom credit is due for the discovery of these peculiar properties of lodestone is as yet unknown. According to some this discovery is credited to Magnes, a Phrygian shepherd, who, one day, while attending his flock of sheep on Mount Ida in Asia Minor, had an experience that greatly surprised him. Happening to touch the iron end of his shepherd's crook to a mass of dark-coloured rock (lodestone), he was astonished to find that the rock appeared to be endowed with life; for it seized hold of the iron so forcibly, at least so the story says, that he was unable to pull it off. Of course, if you or I had such an experience, we would not regard the phenomenon as at all supernatural, but would at once endeavour to find the nature of the force that had drawn the iron towards the rock. You must not forget, however, that in the time of Magnes people believed that all unusual phenomena were due to the direct action of their gods or goddesses, and I imagine that Magnes, on afterwards telling his surprising experience to his acquaintances, ascribed this curious action to one of these supernatural beings.

While there is no doubt that the story of Magnes and his unexpected experience of the power of magnetism is possible, yet it would certainly seem to be improbable. Indeed, in describing Magnes' first observation in magnetism, some declare that it was not the iron at the end of the shepherd's crook, but the stout iron nails in his sandals or shoes that caused the trouble. For my part I am disposed to believe that if either of these stories is credible, of which I must confess having grave doubts, the story of the iron in the crook would seem more probable than the iron nails in his shoes, for I am somewhat uncer-

tain as to whether or not shoes with iron nails were at all common at that early time.

In the opinion of some, the word magnetism has been given to this peculiar property of lodestone from Magnes as its alleged discoverer. Others, however, declare that the word magnetism was derived not from the name of the man, but rather from the name of the country, Magnesia, a province of Asia Minor, where, it is claimed, the phenomenon was at first observed. In the opinion of others, the word magnetism is derived from the Latin word *magnus*, meaning heavy, or great, from the well-known fact that lodestone or iron ore is between five and six times heavier than an equal volume of water.

It would appear, however, that the peculiar properties of magnetism, as possessed by lodestone, were known to the world for many, many years before the time of the shepherd Magnes. There seems to be but little doubt that, long before this, the Chinese had discovered the directive powers of lodestone and had utilised these powers in a variety of compass needle employed, for the purpose of guiding them not across the ocean, but across the almost trackless plains that cover some portions of their country.

Duhalde, in his history of China, claims that the Chinese employed magnetism for the purpose of determining direction as early as 2600 B. C.; that when the Emperor Whang-ti, the third Emperor of China, had given battle to one Chi-yew, he utilised this strange property of the lodestone as follows. Quoting from Duhalde:

“Whang-ti attacked and fought three battles with Chi-yew; when, perceiving that the thickness of the fog hindered him from pursuing his enemy, and that the soldiers

strayed from following the right course, he constructed a card which showed them the south and the other three cardinal points, by which means, at length, overtaking Chi-yew, he seized and put him to death. Some say that on the card were engraved the characters of the rat and the horse and underneath a needle to point out the four quarters of the world. We see here at a glance the compass, or something like the compass, of great antiquity and expressly recorded."

It is a significant fact that, in the same book, Duhalde declares that the magnetic needle was invented, not by Whang-ti, but by an uncle of the second Emperor of China of the third dynasty. The prime minister's name was Chen-kung, and the discovery was made at a time when Chen-kung was acting as viceroy to the Emperor, who was then a mere boy.

Duhalde thus describes this latter invention:

"The king of Cochin China sent ambassadors with presents to congratulate the Emperor on having a subject of such exceeding merit as Chen-kung. After they had had their audience of leave to return to their own country Chen-kung gave them an instrument which, on one side, pointed towards the north and on the opposite side towards the south, to better direct them on their way home than they had been directed in coming to China. This instrument was called chi-nan, which is the name the Chinese now give to the sea-compass; whence it is believed that Chen-kung was the inventor of the compass."

This latter date was about 1040 B. C. The difference in the times of the invention of the compass by these two Chinese was great, being 2600 B. C. for the first, and 1040 B. C.

for the second. It is doubtful whether either of these accounts are reliable, although it would seem that there can be no doubt whatever that the discovery of the directing power of magnetism was made by the Chinese at a date much earlier than the times of the Greeks or Romans.

That the early Chinese were acquainted with many of the facts of magnetism may be seen by the study of the etymology of certain Chinese words for the lodestone, words that are known to have been employed from very early times. For example, the Chinese word for lodestone is either "thsu-chy," the lovestone, or "hy-thy-chy," the stone that snatches up iron.

It will be interesting in this connection to call attention to the fact as stated by Sir William Harris in his "Rudimentary Magnetism," that the Siamese word for magnet is "me-lek," or that which attracts or draws iron; while in the Sanscrit language the magnet is called "ayâskanta" or "loving towards iron."

In a similar manner it can be shown that the Chinese were acquainted with the directive power of the lodestone since they called this mineral "tchu-chy" or the "directing stone," while in a certain province of China they call the lodestone "d'ànamtchum" or "the stone that shows the south." Nor were the early Jews ignorant of magnets. In the Talmud, the code of the Jewish civil and canonical law, the magnet is called "achzhàb'th" or the stone that draws or attracts.

The ancient Greeks and Romans frequently referred in their writings to the powers of lodestone.

Thales, one of the earliest Greek philosophers, sometimes called "The Father of Philosophy," who wrote about

the year 600 B. C., was so impressed by the mysterious powers of magnets that he declared they were endowed with a soul, and, therefore, possessed a species of life. About the same time, Pythagoras, another celebrated Greek philosopher, spoke about the directive powers of the magnet.

Plato, another Greek philosopher, refers to the magnet in the year 500 B. C., while Aristotle, who was, perhaps, the most renowned of all the Grecian philosophers, wrote about the magnet in 400 B. C.

But coming now to still later dates we find the Roman poet, Lucretius, referring to the magnet in a philosophical poem entitled "De Rerum Natura." The particular part of the work describing the magnet has been translated by Dr. Busby as follows:

"Now, chief of all, the magnet's power I sing,
And from what laws the attractive functions spring;
The magnet's name the observing Grecians drew
From the magnetic regions where it grew;
Its viewless potent virtues men surprise,
Its strange effects they view with wondering eyes,
When, without aid of hinges, links, or springs,
A pendant chain we hold of steely rings
Dropt from the stone—the stone the binding source,—
Ring cleaves to ring, and owes magnetic force:
Those held superior, those below maintain,
Circle 'neath circle downward draws in vain,
Whilst free in air disports the oscillating chain."

The following additional facts concerning the knowledge the ancients had of magnetism are given by Thomson in his translation of Salverte's "Philosophy of Magic."

Homer, the great Greek poet, in the *Odyssey* (lib. viii, verses 553-563) makes Alcinous inform Ulysses that the Phocæans' vessels were regulated and guided by a spirit; that they are unlike ordinary vessels in that they need neither helmsman nor pilot; that despite the deep darkness of the night, or thick fogs or haze, they are able safely to pass over the ocean without risk of being wrecked.

There can be no doubt that Homer, in the above, asserted that the Phocæans guided their vessels over the sea by the use of magnetic needles or compasses.

In the same book (the *Odyssey*) it is declared that Abaris, a celebrated sage of antiquity, and, moreover, a great traveller, who flourished about 570 B. C., had been presented by the gods with a golden arrow by the assistance of which he could readily find his way over any part of the universe.

It is said that Pythagoras, the Grecian philosopher, who, it is claimed, shared equally with Thales and Xenophanes the honour of being among the first students of the physical sciences, being desirous of learning from Abaris how his golden arrow guided him from place to place; and, being unable to obtain this information, hid the arrow. Abaris, who was then unable to find his way, disclosed the secret to Pythagoras on condition of having the arrow restored to him. Assuming this story to be true, then of course the arrow of Abaris did not consist of gold throughout, but must have been made of a piece of magnetised steel, coated on the outside with gold in order to prevent it from rusting.

The Phocæans were inhabitants of an Ionic city of Asia Minor that was originally settled by a colony from

Athens. The site of the city was on a peninsula extending between the gulfs of Smyrna and Elis. The city possessed an excellent harbour, so that the Phocæans were naturally distinguished as sailors.

As regards the invention of the mariner's compass, which, as we have already seen, was in all probability to be credited to the Chinese, it may be interesting to note that in his "Cosmos," Humboldt, the celebrated scientific traveller, claimed that more than a thousand years before the Christian era, at the time of the return of the Heracles to Peloponnesus, the Chinese employed magnetic cars on which were placed the figure of a man pointing with his outstretched arms to the south. Guided by these cars the people were able fearlessly to cross the almost trackless grassy plains of Tartary. Humboldt also states that, at least seven hundred years before the introduction of the mariner's compass on the seas around Europe, Chinese vessels navigated the Indian Ocean by means of magnetic needles that pointed to the south.

There is considerable difference of opinion as to the date of the introduction of the compass needle into the seas in the neighbourhood of Europe. It would appear, however, beyond question, that the compass needle was employed in navigating the Syrian seas as early as 1242 A. D. This needle, by the way, is said to have consisted of an ordinary sewing needle that had been magnetised by being touched with a lodestone and was then placed on a piece of cork and permitted to float on the surface of water in a vessel.

William Gilbert, who as early as 1600 published a wonderful book called "De Magnete, or the Lodestone," a book we shall more fully refer to in a subsequent chapter,

declares that compass needles were brought from Italy to China in the year 1260 A. D. by one Paulus Venetus.

According to others, however, it was Flavio Gioia, a citizen of Naples, who invented the compass needle in 1320. Whether this is true or not, Gioia's native city, Principati, on the assumed correctness of Gioia's great invention, has ever since that time employed for its coat of arms a flag bearing a picture of the mariner's compass.

That compass needles were in use at about this time may also be gathered from a statement made by one Ludi Verstomanus, who declares that in the year 1500 A. D. he saw a pilot, in the seas of the East Indies, direct the course of his vessel by means of a magnetic needle closely resembling those now used on the ocean.

CHAPTER IV

THE LODESTONE

IN various parts of the world there is found a certain ore of iron called lodestone that consists of two different oxides of iron combined chemically with each other.

The word lodestone, or, as it means, leading-stone, is sometimes spelled loadstone, possibly from the fact that the stone is able to hold a fairly considerable weight or load in the shape of soft iron. It is claimed by others that the word loadstone is derived from a Saxon word meaning "to lead." I think, however, that the spelling lodestone is more correct than loadstone.

Specimens of lodestones are sometimes found strongly magnetised, and, therefore, possessing the power not only of drawing or attracting particles of iron towards them, but also, when so placed that they are free to move in a horizontal plane, of pointing, approximately, to the earth's north. It is for this reason that such specimens are called "natural magnets."

The particular oxide of iron known as lodestone takes its name "magnetic oxide of iron" from the fact that it is capable of being readily magnetised. For the same reason it is also called "magnetite."

Lodestones are found in many parts of the world. They were obtained by the ancients mainly from Magnesia, in Asia Minor. It would seem that the ancients had their

attention first called to these stones by their ability to attract or hold on to small pieces of iron. This supernatural or magic property is what at that time made the lodestone famous throughout the world. As we have already seen, lodestones also possess the power of pointing or showing the way towards the north and are, therefore, known as leading stones. The lodestone is also sometimes called heraclian stone.

For the sake of those of my readers who are unacquainted with chemistry, I will say that magnetite, or the magnetic oxide of iron, consists of what in chemistry is called the sesque-oxide of iron combined with another oxide of iron known as the prot-oxide of iron. The sesque-oxide of iron consists of three atoms of iron combined with three atoms of oxygen, and is generally represented in chemical symbols by Fe_2O_3 , where the symbol Fe indicates one atom of iron, and the symbol O one atom of oxygen, while the figures 2 and 3 placed after these symbols, indicate that the sesque-oxide of iron consists of two atoms of iron combined with three atoms of oxygen. In a similar manner, the prot-oxide of iron is represented chemically by the symbols FeO.

Now FeO, or the prot-oxide of iron, possesses basic chemical properties, or is what chemists call a base; while the sesque-oxide Fe_2O_3 possesses acid properties, or is what chemists call an acid. As you will know when you study chemistry, acids and bases possess mutual attractions for each other, and, entering into combination, produce substances called salts.

The magnetic oxide of iron, or the lodestone, is a salt of this character, consisting of the combination of the basic

and acid oxides of iron. It may be represented in chemical symbols by the formula $\text{FeO} + \text{Fe}_2\text{O}_3 = \text{Fe}_3\text{O}_4$.

I wish to say here that I do not expect all my readers to understand the preceding paragraphs. Read them over carefully and, if too difficult to understand, pass them by. It is enough if you have gained the idea that the ore of iron known as lodestone is a peculiar oxide of iron, that, like hardened steel, not only possesses the power of being magnetised when touched by lodestone, or by a steel magnet, but also possesses the power of almost indefinitely retaining this magnetism. If, in after years, when you have studied chemistry, you happen again to read this account of the magnetic oxide of iron, you can see how easy it is to understand what so troubled you in your younger years when you knew little or nothing about chemistry.

Different specimens of magnetite or lodestone vary in colour from a reddish black to a deep grey. The mineral occurs both in a massive state as well as in well-formed crystals. It also frequently occurs as magnetic iron sand. Ingenious forms of apparatus, known as magnetic separators, have been invented by Mr. Thomas Edison and others. These contrivances possess the power of readily separating the particles of magnetic sand from the dirt and dust with which they are mixed.

Having thus explained the general appearance of lodestone or magnetic oxide of iron, let us now examine somewhat carefully its ability to draw towards it or attract particles of iron, and afterwards hold on to them with considerable force. Suppose a lodestone be rolled in a mass of iron filings. On its removal, and after a few gentle

taps with a heavy lead pencil or light stick, it will be found that all the filings will fall off the surface of the stone except at two points on opposite sides, where they continue to hang on with considerable force.

The two opposite points at which the iron filings have collected on the lodestone correspond to what we have called poles in the case of the compass needle before referred to in Fig. 1.

If, instead of rolling the piece of lodestone in iron filings, it be supported on a stand *T*, as shown in Fig. 2, it will

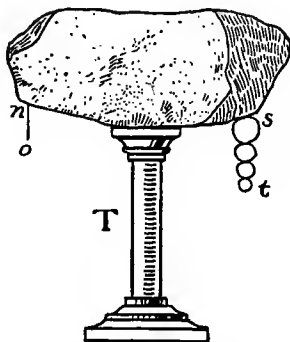


FIG. 2.—A LODESTONE

be found that there are certain points on its surface, as for example at *n* and *s*, on opposite faces, where it possesses sufficient magnetic attraction to sustain a series of short needles of iron *n o*, or a series of soft steel rings, *s t*, suspended successively one on the other solely by reason of the attraction of the invisible attendants of the magnet.

If you carefully examine the preceding figure, you can see the way the rings of soft steel are suspended to one

another, in a chain from the poles of the natural magnet. This is what the poet Lucretius referred to, in the quotation given in the preceding chapter:

“When, without aid of hinges, links, or springs,
A pendant chain we hold of steely rings
Dropt from the stone—the stone the binding source—
Ring cleaves to ring and owns magnetic force.”

The actual attractive power of the lodestone is not, as a rule, great. Generally, it is far less than the force possessed by the ordinary steel bar horseshoe magnets that I hope most of you have seen and experimented with. Generally speaking, natural magnets or lodestones are seldom able to lift their own weight of soft iron or steel. Indeed, as a rule, the weight they can lift is much less than their own weight. Sometimes, however, unusually powerful specimens of lodestones have been found that are capable of lifting several times their weight of soft iron. This is especially the case with small lodestones.

It is said that Sir Isaac Newton, the well-known English philosopher, who discovered the force of gravitation, owned a small piece of lodestone, or natural magnet, that he had set in a hand ring. Although this magnet weighed only three grains, yet it was able to lift a mass of iron weighing seven hundred grains; or, in other words, was able to lift about 233 times its own weight.

There is always a danger, when an uneducated person attempts to describe a natural phenomenon, of his drawing the long bow, or, as the boys call it, “batting them out.” I think there can be but little doubt that the Phrygian shep-

herd, Magnes, if such a man ever existed, drew largely on his imagination when he declared that the mass of lodestone found on Mount Ida held on to the mass of soft iron at the end of his shepherd's crook with such force that he was unable to separate it, or that, in a similar manner, the mass of lodestone, on which he happened to stand, so attracted the iron nails of his sandals as to hold him fast to the earth.

There is something so mysterious about the invisible force lurking in a mass of lodestone, ready to seize and hold on to any mass of iron that may come in its neighbourhood, that the lodestone has, from very early times, been a natural object offering no little inducement for travellers to "bat out" their experiences.

In Guillemin's "Electricity and Magnetism" the following passage occurs:

"According to Pliny there are near the Indus two mountains, one of which attracts iron and the other repels it; at a certain position a traveller who has nails of iron in his boots on one of the mountains cannot place his feet on the ground, whilst on the other his feet remain fixed to the ground."

I need hardly say that this is an exceedingly improbable story.

But it is in that great story book which I hope all of you have read—if you have not done so, I would advise you to get a copy as soon as possible—that the wonders of the lodestone are described in a manner which certainly deserves the first prize for "batting them out." I am referring to the story of "The Third Royal Calendar," as given in "The Arabian Nights' Entertainment." It re-

lates the wonderful adventures of Prince Agib, the son of King Cassib. I will let him tell this story himself.

“I am called Agib, and am the son of a king, whose name was Cassib. After his death I took possession of his throne, and established my residence in the same city in which he had made his capital. This city, which is situated on the sea-coast, has a remarkably handsome and safe harbour.”

“I resolved to go in search of discoveries beyond my islands. For this purpose I equipped only ten ships, and embarking in one of them, we set sail.

“During forty days our voyage was prosperous; but on the night of the forty-first the wind became adverse, and so violent that we were driven at the mercy of the tempest, and thought we should have been lost. At the break of day, however, the wind abated, the clouds dispersed, and the sun brought fine weather back with it. We now landed on an island, where we remained two days, to take in some provisions. Having done this, we again put to sea. After ten days’ sail we began to hope to see land; for since the storm we had encountered, I had altered my intention, and determined to return to my kingdom, but I then discovered that my pilot knew not where we were. In fact, a sailor, on the tenth day, who was ordered to the masthead for the purpose of making discoveries, reported that to the right and left he could perceive only the sky and sea, which bounded the horizon, but that straight before him he observed a great blackness.

“At this intelligence the pilot changed colour, and

throwing his turban on the deck with one hand, he smote his face with the other, and then cried out, 'Ah, Sire, we are lost; not one of us can possibly escape the danger in which we are.' I asked him what reason he had for this despair. 'Alas, Sire,' he answered, 'the tempest has so driven us from our track, that by midday to-morrow we shall find ourselves near the blackness, which is nothing but a black mountain, consisting entirely of a mass of lodestone, that will soon attract our fleet, on account of the bolts and nails in the ships. To-morrow, when we shall come within a certain distance, the power of the lodestone will be so violent, that all the nails will be drawn out, and fastened to the mountain; our ships will then fall to pieces, and sink. This mountain towards the sea is entirely covered with nails that belonged to the great number of ships of which it has proved the destruction. It is very steep, and on the summit there is a large dome, made of fine bronze, which is supported on columns of the same metal. Upon the top of the dome there is also a bronze horse, with the figure of a man upon it; and there is a tradition, Sire, added he, 'that this statue is the principal cause of the loss of so many vessels and men, and that it will never cease from being destructive to all who shall have the misfortune to approach it until it be overthrown.' The pilot having finished his speech, renewed his tears, which excited those of the whole crew. As for myself, I did not doubt that I was now approaching the end of my days.

"The next morning we distinctly perceived the black mountain; and the idea we had formed of it made it appear still more dreadful and horrid than it really was. About midday we found ourselves so near it, that we began to

perceive what the pilot had foretold. We saw the nails, and every other piece of iron belonging to the vessel, fly towards the mountain, against which, by the violence of the magnetic attraction, they struck with a horrible noise. The vessel then immediately fell to pieces, and sunk to the bottom of the sea. All my people were lost; but God had pity upon me, and suffered me to save myself by laying hold of a plank, which was driven by the wind directly to the foot of the mountain. I did not experience the least harm, and had the good fortune to land in a place where there were steps, which led to the summit. I was much rejoiced at sight of these steps, for there was not the least piece of land either to the right or left upon which I could have set my foot to save myself. I returned thanks to God, and, invoking His holy name, began to ascend the mountain. The path was narrow, and so steep and difficult that, had the wind been at all violent, it must have blown me into the sea. I arrived at last at the summit without any accident, and, entering the dome, I prostrated myself on the ground, and offered my thanks to God for the favour He had shown me.

“I passed the night under this dome; and while I was asleep, a venerable old man appeared to me, and said, ‘Agib, attend; when you awake, dig up the earth under your feet and you will find a brazen bow with three leaden arrows, manufactured under certain constellations, in order to deliver mankind from many evils, which continually menace them. Shoot these three arrows at the statue: the man will then fall into the sea, and the horse at your feet, which you must bury in the same spot from whence you take the bow and arrows. This being finished, the sea

will begin to be agitated, and will rise as high as the foot of the dome, at the top of the mountain. When it shall have risen thus high, you will see a small vessel come towards the shore with only one man in it, who holds an oar in each hand. This man will be of brass, but different from the one that was overthrown. Embark with him without pronouncing the name of God, and let him conduct you. In ten days he will have carried you into another sea, where you will find the means of returning to your own country in safety; provided, as I have already told you, you forbear from mentioning the name of God during the whole of your voyage.

“Such was the disclosure of the old man. As soon as I was awake, I got up, much consoled by this vision, and did not fail doing as the old man had ordered me. I uncovered the bow and the arrows, and shot them at the statue. With the third arrow I overthrew the man, who fell into the sea, while the horse lay at my feet. I buried it in the place where I found the bow and arrows, and while I was doing this, the sea rose by degrees, till it reached the foot of the dome on the summit of the mountain. I perceived a vessel at a distance coming towards me. I offered my benedictions to God at thus seeing my dream in every respect proving a reality. The vessel at length approached the land, and I saw in it a man made of brass, as had been described. I embarked, and took particular care not to pronounce the name of God. I did not even utter a single word. When I sat down, the brazen figure began to row from the mountain. He continued doing so without intermission till the ninth day, when I saw some islands, which made me hope I should soon be free from every

danger that I dreaded. The excess of my joy made me forget the order that had been given me as a security. 'Blessed be God!' I cried out, 'God be praised!'

Of course, you will not believe this ridiculous story; for, as I have already said, it justly deserves to receive the prize for improbability. It is true, as I shall describe in subsequent chapters of this Wonder Book, that magnets of wonderful power and strength can readily be made. But the power of a magnet to attract iron very rapidly decreases with the distance, so that I doubt very much whether

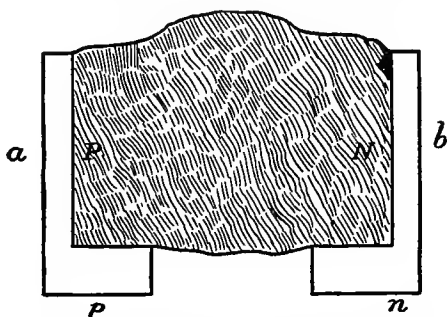


FIG. 3.—LODESTONE WITH ARMATURES

it will ever be possible to produce a magnet, no matter what its size, that will be able to draw towards it a ship at a distance of many miles, and, then, before the ship reached the magnet, to loosen the iron bolts and nails with which the ship was held together.

That lodestone possesses directive power can be shown by suspending a fragment of it by a silk thread. Under these circumstances, after swinging to-and-fro for a few

moments, the lodestone will come to rest with one end pointing approximately to the north, and the opposite end approximately to the south, just as did the compass needle already referred to in the preceding chapter; for these ends constitute the poles of the natural magnets of which the lodestone consists.

When it is desired greatly to increase the power of a lodestone to draw or attract masses of iron towards its poles,

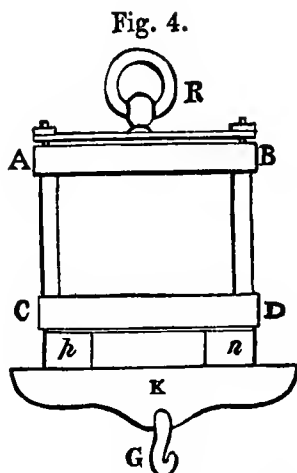


FIG. 4.—ARMATURE AS “KEEPER”

it is provided with pieces of soft iron called armatures. You will better understand the manner in which these armatures are placed on a mass of lodestone by carefully examining Fig. 3. Here a mass of lodestone with fairly strong poles, *N* and *P*, as its opposite faces, is squared off by a lapidary's wheel and made smooth and regular, so that pieces of soft iron, *a p*, and *b n*, shaped as shown, can

be fitted closely to the polar faces. When placed in this manner, since the pieces of soft iron instantly become magnetised, two poles *p* and *n* are produced on the lower face of the lodestone.

As soon as the masses of soft iron are fixed to the polar faces of the lodestone the three pieces are bound firmly together, either by a cap of silver, or by plain metallic bands of brass, *AB* and *CD*, as shown in Fig. 4. For convenience in lifting the mass, a ring, *R*, is placed as shown in the upper cap, while a piece of soft iron, *κ*, called an armature, is placed across the artificial poles *p* and *n*, so as to unite them. The effect of the armature is to increase the strength of the magnet poles, as well as to prevent the magnet from readily losing its magnetism. It is because of this latter property of retaining or keeping the magnetism in the magnet, that the armature is sometimes called a keeper. A hook, *α*, is frequently attached to the keeper, *κ*, as shown, so as to permit a scale pan to be hung to it. It is a curious fact that if, from day to day, additional weights are slowly added to the pan, a lodestone thus provided with an armature or keeper will be able to sustain a greater weight than when all the weights are added at the same time.

CHAPTER V

MAGNETS THAT CAN READILY REMEMBER THEY HAVE BEEN MAGNETISED

AN artificial magnet, as its name indicates, differs from a natural magnet only in that, instead of being found in the ground already magnetised, it has had its magnetism imparted to it artificially. This can be done in a variety of ways, only one of which, contact with another magnet, will be considered in this chapter.

If a piece of soft iron or soft steel is brought into contact with either of the poles of a bit of lodestone, it will thereby become magnetised, and will form what is known as an artificial magnet. The same thing will happen if instead of a piece of soft iron or steel a piece of hardened steel is employed. Then, however, there will be this difference: that whereas the piece of soft iron or steel will retain its magnetism only while it remains in contact with the natural magnet, instantly losing it on removal, the bit of hardened steel will retain its magnetism for days or even for years after it has been removed.

Generally speaking, therefore, there are two kinds of artificial magnets; *i. e.*, temporary magnets, or those that only retain their magnetism while under the influence of the magnetising force, and permanent magnets, or those that retain their magnetism for an indefinite time after being removed from the influence of the magnetising force.

Since, as has already been stated, a natural magnet (that

is, a piece of lodestone) retains its magnetic properties almost indefinitely, it is evident that such magnets can properly be called permanent magnets. As a rule, however, the name permanent magnet is limited to an artificial magnet made by magnetising hardened steel.

Various forms are given to permanent magnets. The commonest is the form called a bar magnet. This consists of a straight bar of steel with right-angled edges, such as is represented in Fig. 5.

The bar magnet is sometimes provided with a depression at the centre *C* of one of its faces, so as to permit it to be supported on a needle point. This allows it, when so desired, to be used as a compass needle for determining



FIG. 5.—A PERMANENT BAR MAGNET

directions. As a rule, in order appreciably to decrease their weight, magnetic bars intended for compass needles are made much thinner than regular bar magnets.

The common straight bar magnets intended for use as magnetic needles are generally lozenge-shaped. Such a permanent magnet is called a magnetic needle. In magnetising a magnetic needle, care should be taken that the north and south poles so produced shall fall exactly at its needle-shaped points or extremities.

Magnetic needles are generally provided with a depressed or conical shaped jewelled cup of agate. This decreases the friction at the needle point and corresponds to the jewels employed in watches for the reception of the watch pivots.

In delicate instruments like watches, or in the delicate electrical instruments employed for the measurement of electric currents, these jewels are sometimes formed of rubies and even of diamonds, on account of the great hardness of these precious stones. Ordinarily, however, a bit of hard agate answers satisfactorily all the requirements of an ordinary magnetic needle.

Various shapes are given to permanent magnets. Sometimes the ends are bent around so as to approach each other in the shape of the letter U, as represented in Fig. 6.

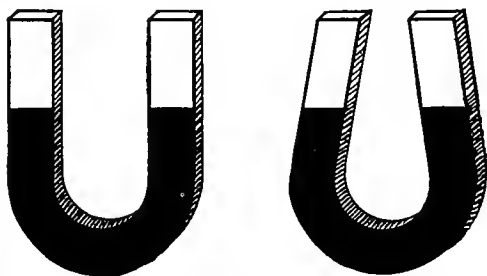


FIG. 6.—U-SHAPED AND HORSESHOE MAGNETS

In the U-shaped magnet, as will be observed, the two legs of the U are parallel to each other. In most cases, however, the legs are inclined towards each other, thus giving the magnet a horseshoe shape, as in Fig. 6. The former is known as a U-shaped magnet and the latter as a horseshoe magnet. In either of these forms, the magnetising force is so applied as to bring the north and south poles to the extremities of the bar. As will be explained in a subsequent chapter, either the U-shaped or the horseshoe magnet is capable of sustaining a greater weight than a straight bar magnet, not only on account of the

simultaneous action of both poles, but also for another reason that later will be thoroughly explained.

The strength of a permanent magnet depends not only on the strength of the magnetising force which has been employed in magnetising it, and on the character of the steel from which the magnet has been made, but also on the degree of hardness which the steel has acquired before being magnetised. It is true that the steel which is brought to the blacksmith for the purpose of being forged into the desired shapes does not generally require any softening or annealing, since it is then nearly always in a soft condition. If, however, he happens to receive it in a hardened condition it can readily be annealed, or have its hardness drawn, by heating it to a certain high temperature, depending on the degree of tempering, and then permitting it to cool slowly.

Generally speaking, the softened or annealed steel, after being forged or wrought into the desired shape, is raised to a high temperature and then hardened by suddenly plunging it in a bath of cold salt water or chilled oil.

The strength of a permanent magnet depends not only on the strength of the magnetising force, but also on the character of the steel, and the degree of hardening to which it has been subjected.

When hardened by sudden chilling, steel may become extremely hard and brittle. If, for example, a specimen of good steel is brought to a white heat and then suddenly chilled, it may become so hard that it is impossible to cut it by a file. In this condition it is sufficiently hard to cut glass like a diamond.

When it is desired to take away some of this hardness,

the process called annealing, above referred to, is employed. In this process, the piece of steel to be annealed is placed on the surface of a red-hot plate of iron. As the heat slowly passes from the plate into the steel its surface undergoes changes of colour. The first colour that appears is a reddish or purplish tint; then a yellow or straw colour, which gradually increases in depth, when it changes to a deep blue, until finally the steel becomes white hot. It is by means of these changes in colour that the amount of heating to which the steel has been subjected and the consequent amount of annealing, or the extent to which the hardness of the steel is decreased when subsequently slowly cooled, can be regulated. If, on the appearance of any of these colours, the steel is promptly removed from the hot iron plate and then permitted slowly to cool, it will be annealed or softened to a degree that will be least in the case of the reddish or purplish tint, and greatest in the case of the white heat, when all its hardness will be removed.

If the article that is being tempered is removed from the plate as soon as it acquires a straw colour, and is then slowly cooled, the steel will have lost but comparatively little of its hardness and will then be suitable for such tools as drills, so that this temper is sometimes known as a "drill-temper." When, however, the steel has become of a blue colour, it is suitable for the manufacture of springs, so that this temper is sometimes called a "spring-temper."

Generally speaking, when it is desired that a magnet shall retain its magnetism for a long time, the steel is tempered as hard as possible. While, however, magnets made from such steel are able to retain their magnetism

almost indefinitely, unless the magnetising force is great they are not as powerful as they would be had the steel been less hard. Indeed, in almost any case it is found preferable to harden the steel as much as possible, to draw its temper by heating to a violet straw colour, and then, to remove it from the source of heat, permitting it to cool gradually. It will then be sufficiently hard to retain its magnetism fairly well and yet at the same time to acquire a fairly powerful magnetisation.

Dr. William Scoresby, a well-known English Arctic explorer and physicist, who made and published a valuable series of investigations in magnets, between the years 1839-1852, gave especial attention to the conditions under which the best steel magnets are made. While it is true that such great improvements have recently been made in the manufacture of steel, since the time of Dr. Scoresby's investigations, as to render invalid some of his conclusions, yet these general conclusions are so valuable that it will be well briefly to recite them.

As regards the character of steel best suited for the production of permanent magnets, Dr. Scoresby calls attention to the fact that one must bear in mind whether it is desired that the magnet shall possess great strength or power; shall be able to retain its magnetism for a long time; or shall possess both of these properties. As a rule, supposing the steel to be good, the greater the hardness, the longer will the magnet retain its magnetism. If, however, it is desired that the magnet shall possess its maximum of strength, then, roughly speaking, the softer the steel, the stronger the magnet. A happy mean is found in a condition of hardness lying near the maximum, and

obtained by drawing the temper at about the colour of a yellow straw. Then, as already mentioned, a fairly strong magnet, as well as a fairly permanent magnet, will be produced. In a subsequent chapter I will point out at greater length why it is that the maximum magnetic strength is obtained with soft steel rather than with hard steel.

Summarising, Scoresby drew the following conclusions from his investigations:

When steel is employed in thin plates that have been made quite hard, the variety of steel known as "shear-steel" possesses a greater capacity in the individual plates than would a variety known as "blister-steel" or as "cast-steel."

Cast steel, being capable of great hardness, is the most effective for the production of large, straight bar magnets, whether made in single massive plates or by a combination of thin plates.

The better the iron out of which the cast steel is made, the better the magnet.

Scoresby gives the following advice as regards the kind of steel and the best degree of hardness or amount of tempering.

"For all large and massive single or compound magnets of the straight-bar form, use the best cast-steel made quite hard; for horseshoe magnets, if single, cast-steel annealed from file hardness at a temperature of about 550° F., or shear-steel a little reduced; and for compound horseshoe magnets, cast-steel annealed at 480° F. to 500° F., or shear-steel perfectly hard; for compass needles, if single and heavy, such as suited for stormy weather, hard cast-

steel; if light or of moderate weight, whether single or compound, the best cast-steel annealed at 500° F. or 550° F. or hard shear-steel or hard cast-steel from Bradford iron; and for very light needles, or other small magnets, the best cast-steel annealed at the heat of boiling oil."

Various rules have been given as regards the production of permanent magnets, according to the purpose for which the magnets are to be employed; for, as we shall afterwards explain, magnets can be divided into two classes; those known as portative magnets or able to exert a powerful attraction on their keepers; and those known as attractive magnets or that possess the ability to attract their armatures with a certain degree of force at a comparatively great distance.

The width of the magnet should not greatly exceed one-twentieth of its length, nor the thickness one-third or one-fourth of its width.

In a horseshoe magnet the distance between the two poles is generally less than the width of the ends of the magnets. The faces of magnets should preferably be kept highly polished.

Where a number of bar magnets are to be put away in the same drawer, care should be taken that they do not touch one another, since wherever the pole of one magnet touches the surface of another, it produces a permanent opposite pole which cannot fail greatly to interfere with the action of the magnet. Nor is the direction in which the magnets are placed on the bottom of the drawer a matter of indifference. A magnet will retain its magnetism much better when placed in a due north and south direction, with its north pole pointing approximately to the earth's north,

than it would if placed in any other direction. Moreover, where several magnets are to be placed together in the same drawer, when this rule of placing the magnets in a north and south direction cannot be applied, it is then safer to place the magnets parallel to one another with their opposite poles facing.

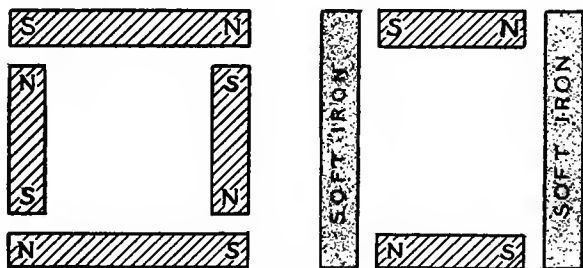


FIG. 7.—HOW TO PUT AWAY MAGNETS

When four such magnets are put away together, they should be placed as shown in Fig. 7, rather near together.

Instead, however, of employing magnets, as in the left-hand figure, masses of soft iron may be substituted, as shown in the right-hand figure.

Since, if placed loosely on the bottom of the drawer, the magnets are apt to touch one another in opening or shutting the drawer, they should be fixed to the bottom by placing them between suitably arranged strips of wood.

CHAPTER VI

MAGNETIC BATTERIES

HAVE you ever noticed that in fairy stories the giant killers are generally much smaller than the average sized man? This, you will remember, was the case with that exceedingly small chap known as Hop-o'-my-Thumb. I think this is only another way of saying that a small man with a well-developed brain will almost always get the better of a big man with little or no brains. I will not stop here to tell you the story of Hop-o'-my-Thumb, for most of you have already read it. I will merely tell you enough of the story to illustrate my point.

There was once a man and his wife who were very poor and earned their living by collecting faggots of wood in the forest. They had several children, all of them boys. The youngest boy was exceedingly small, so small, indeed, that he was not much bigger than a man's thumb, and was therefore called Hop-o'-my-Thumb. But, though so very small, his brains, so far as their ability to do good thinking was concerned, were much larger than either those of his brothers, or of a great ogre he subsequently killed.

Now it is exactly the same with magnets, whether they be natural or artificial, as to their ability to do the things that magnets are ordinarily expected to do; that is, to draw masses of iron towards them, or to point out to people the direction of the north and south; or (remembering what Thales believed, that magnets possessed a mind or a soul), what might be called the intelligence of a magnet is apt

to be found in greater strength or intensity in small magnets than in large magnets.

You will remember that I have already called your attention to the fact that, perhaps, in proportion to its size, the strongest natural magnet known was that possessed by Sir Isaac Newton, the English philosopher. This magnet consisted of a piece of lodestone so small that Newton could readily carry it in a ring which he wore on one of his fingers. It was small as compared with most natural magnets, quite as small, indeed, if not smaller, than Hop-o'-my-Thumb was in comparison with the ogre, and yet this little lodestone, small as it was, was capable of exerting a force greater in proportion to its weight than could much larger pieces of lodestone; for this little magnet was able to lift 233 times its own weight.

You are now ready to understand that, if you wish to obtain a strong permanent magnet of steel, you must employ not a heavy, large mass of steel, but, on the contrary, a number of small thin pieces of steel. Many years ago, in the endeavour to obtain strong steel magnets, great masses of hardened steel were fashioned into the proper shapes and magnetised by the strongest magnet that could be obtained. But somehow or other this plan did not work satisfactorily. The magnets, though large, were far less strong than had been expected. A number of separate magnets still of fairly large size were piled together with all their north poles lying over one another, and of course with all their south poles in the same position. Although a much stronger magnet was obtained in this manner than where a single large piece of steel had been employed, yet it was not as strong as they had expected it to be. They

had apparently yet to discover that, if they wished to obtain great power in a single magnet, they would be obliged to use a great number of little magnets so placed that all could act in the same direction.

The idea of building up a magnet by piling together a number of smaller separate magnets with their like poles together, so that all the smaller separate magnets could act as a single magnet, appears to have first occurred, many years ago, to an Englishman named Dr. Gowan Knight, who lived in London. Since his time this idea has been greatly improved upon by a number of other scientific men, so that at the present time "compound magnets," or, as they are sometimes called, "magnetic batteries," are now constructed that possess great strength. You will see from what I have said above that a magnetic battery consists of a number of separate smaller magnets so combined that all of the magnets are capable of acting as one.

Knight's first magnetic battery was not as strong as it would have been had he not piled together the separate magnets of which it consisted so that they touched one another. The cause of this partial failure was first discovered by Charles A. Coulomb, a French scientist, who made a research in magnetic needles that was so much thought of by the French Academy that they awarded him a prize. Coulomb pointed out that when the separate magnets were placed together they acted on one another so as to decrease their strength; that in order to obtain the best results the magnets in the centre of the pile should be a little longer than those on the outside.

Dr. Scoresby, already referred to, made the additional

important discovery that if the separate magnets, instead of being placed in actual contact with one another, were separated by small air spaces, they could all be made of the same length, and that then the strength of the magnetic battery would be nearly equal to the strength of the sum of its separate magnets.

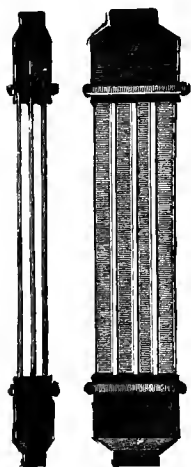


FIG. 8.—A COM-
POUND MAGNET OR
MAGNETIC BATTERY

Fig. 8 represents a magnetic battery with separate magnets of the same length separated from one another by small air spaces. As can be seen, this battery consists of a combination of twelve separate magnets with their similar poles placed directly over each other in three rows of four each. An examination of the figure will show that these magnets are five or six times as broad as they are thick.

But a magnetic battery so constructed would fail to possess any marked strength if its ends or poles were not provided with heavy pole pieces of soft iron. Just why it is that soft iron is capable in this way of so greatly increasing the strength of the magnetic battery will be explained in a subsequent chapter.

It was Dr. Knight who discovered that it is necessary to employ heavy pole pieces of soft iron in order to obtain the best results with magnetic batteries.

It may interest you to know the form that Dr. Knight gave to one of the largest of these magnetic batteries that

he ever constructed. This battery consisted of two great magazines consisting in all of many bars of hardened steel, each bar being fifteen inches in length, one inch in width, and half an inch in thickness. The single bars, instead of being made in a single length, were made in four lengths, thus showing that Knight thoroughly understood the fact that, to obtain the greatest magnetic strength, he must use small magnets. In each magazine these bars were made up of sixty bars arranged in six rows or courses of ten bars each, set edgewise, so that there was a breadth of ten bars and a depth of six bars, or in all sixty bars, and since each bar consisted of four separate ones, a total of 240 bars in each magazine, or of 480 in the two magazines.

All the north poles of the separate magnets were turned in the same direction, so that the separate smaller magnets constituting each bar had their dissimilar poles in contact. In order to keep the joints of the bars close together, they were securely held in position.

You can readily understand that this magnetic battery must have been quite heavy. Indeed, each magazine weighed five hundred pounds, and it was necessary to mount them, not only so that they could be moved on a horizontal axis something like the trunnions of a cannon, and afterwards securely fixed in any position, but also to place each on a four-wheeled truck, for convenience in moving them towards or from one another, as well as from place to place.

It is not known exactly how strong Knight's big magnet actually was when first made. If, however, it had not lost much of its magnetic strength when Michael Faraday tested it about the year 1830, it was by no means as

strong as many magnets are made to-day; for Faraday found that when a cylinder of soft iron, a foot in length and three-quarters of an inch in diameter, was placed across

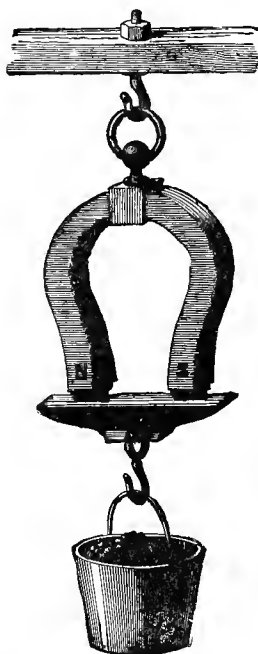


FIG. 9.—A MAGNETIC HORSESHOE BATTERY

the dissimilar poles of the two magazines, a weight of a hundred pounds was able to break down its attractive power. Now, as I shall afterwards describe to you, magnets can now be made, much smaller in weight and size, that can sustain a weight of several thousand pounds placed between

their poles. Notwithstanding this fact, however, Dr. Knight deserves great credit for the wonderful improvement he then made in permanent magnets. Although his magnets cannot compare with those made to-day, yet they appear to have been much stronger than those made during his time in any other way.

Knight's magnetic battery was made for the purpose of obtaining a powerful magnet capable of magnetising a bar of steel when simply placed between the opposite poles of the two magazines.

Magnetic batteries are also made in the form of horseshoe magnets. Fig. 9 represents a form of compound horseshoe magnet in which a number of separate thin steel bars are placed as shown with their similar poles together, and firmly bound together by any suitable means. In the case of the magnet shown in this figure the two compound poles N and S are provided with a massive armature of soft iron. This armature is provided with a hook for the support of a weight placed in a bucket. The top of the magnet is provided with a ring for hanging it to a suitable support.

Another form of horseshoe magnet consists of two separate magnetic batteries placed parallel to each other with their poles reversed.

It is an interesting fact that none of the magnetic batteries above described, are able to sustain their greatest load immediately after the armature has been brought in contact with their poles. On the contrary, if weights are slowly added from time to time, the magnets will be able to sustain a much heavier load than if the weights were added almost immediately after the armatures are brought

in contact with the poles. When, however, the load finally becomes so great as to tear away the armature from magnet poles, the magnet loses this extra strength and can only again be made to hold the extra weight by slowly adding it, as before, day after day.

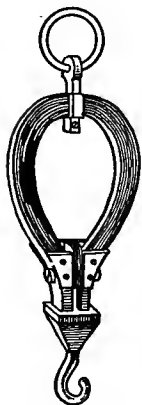


FIG. 10.—
JAMIN'S
HORSESHOE
BATTERY

It appears that in the construction of compound magnets, or magnetic batteries, the best results are obtained under the following conditions:

(1) The separate magnets should possess the same dimensions and should be formed of steel of the same quality and hardness.

(2) The separate magnets should be placed at equal distances from one another, and be separated by some not readily magnetised material, such as air.

(3) The separate magnets should be thin and of the "spring-temper."

A very powerful form of horseshoe magnetic battery has been constructed by the French physicist, Jamin. This consists, as represented in Fig. 10, of thin strips of ribbon steel, separately magnetised. Jamin found that the strength of such a battery was greatly increased by increasing the size and mass of the soft iron pole pieces. For example, while a magnetic battery of this form, containing three strips of steel without any pole piece, was able to lift a weight of only four kilogrammes (8.80 pounds avoirdupois), when provided with suitable pole pieces of soft iron, it could lift a

weight of 140 kilogrammes (308.6 pounds avoirdupois). It was necessary, however, that the separate magnets be magnetised separately, and provided afterwards with pole pieces; for, if they are magnetised after being put together, their strength will be sensibly decreased.

CHAPTER VII

MAGNETIC LIKES AND DISLIKES

As we have already seen, the compass needle possesses two poles, one of which, under the influence of the earth's magnetism, points, approximately, to the earth's north pole, and the other to its south pole. In a well constructed compass needle the magnetisation is such that these two poles are situated at exactly opposite extremities of the needle.

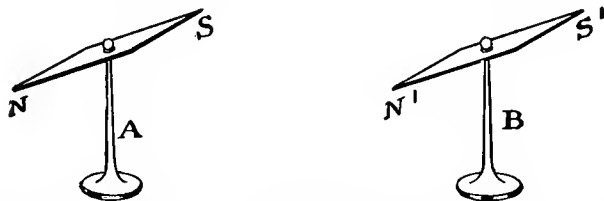


FIG. 11.—MUTUAL ACTION OF TWO COMPASS NEEDLES ON EACH OTHER

All magnets must possess at least two poles. They may, however, possess more than two.

There is a mysterious property possessed by magnets that has not as yet been mentioned. The poles of a magnet are not only able to attract another magnet; they may also, under certain circumstances, repel or drive away a magnet from them. In other words, magnet poles possess repulsion as well as attraction. Let us endeavour, therefore, thoroughly to understand this peculiar property.

Suppose a compass needle A, such as shown in Fig. 11, be placed on a table. It will come to rest with its north

pole N pointing approximately to the north pole of the earth, and its south pole S pointing approximately to the earth's south pole. Moreover, if another compass needle B be placed near it on the same table, but further apart than the length of either of the needles, both needles will come to rest pointing approximately to the north and south, or will be approximately parallel to each other as shown.

The two compass needles having assumed the positions represented in the above figure; *i. e.*, parallel to each other, and pointing nearly due north and south, suppose we lift one of the needles, say B, from its support, and, holding it in the hand, bring its north pole N^1 into the neighbourhood of the north pole N of the needle A, without, however, permitting the poles to touch each other. Instantly, instead of the poles attracting each other, thus causing the suspended needle A to be attracted so as to point towards the north pole N^1 of the approached needle B, a marked repulsion will at once take place. The north pole of B will suddenly repel the north pole of A, forcibly turning it around until its opposite or south pole S, after swinging to-and-fro for a few moments, will come to rest pointing towards the north pole of B. By means of this simple experiment, we can see that the north pole of one magnet repels the north pole of another magnet, as if it actually disliked it, just as we have already seen that the north pole of one magnet attracts the south pole of another magnet as if it liked it.

But let us now try the other pole S^1 , of the magnet B. If this pole be approached to the south pole of the supported needle A, a repulsion will also take place. The south pole of B drives or repels the south pole of A, turn-

ing it around until its opposite or north pole points towards the south pole of B.

Summarising the results obtained by these experiments, we find that a north magnetic pole repels another north magnetic pole; a south magnetic pole repels another south magnetic pole, but that a north pole attracts a south pole, and a south pole attracts a north pole. Briefly, like or similar magnetic poles repel, and unlike or dissimilar poles attract each other.

Suppose now, that instead of placing the compass needle *s N* on the top of a wooden table, as in the preceding figure, it is placed at the middle of a bar magnet *N S* as

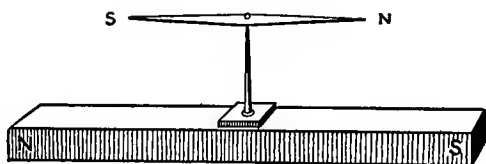


FIG. 12.—COMPASS NEEDLE PLACED ON BAR MAGNET

represented in Fig. 12. Then its poles, instead of pointing approximately north and south, will point directly towards the opposite poles of the bar magnet, and this will occur no matter in what direction the bar magnet may have been placed on the table. In other words, whether the bar magnet has been placed so as to point with its north and south poles to the north and south poles of the earth, or with its north and south poles due east and west, or in any other direction, the north and south poles of the compass needle will point directly to the south and north poles of the bar magnet on which it has been placed.

It is evident then that the polarity of any magnet can readily be determined by means of the properties possessed by its opposite poles. Suppose a compass needle has been permitted to come to rest pointing approximately north and south, and it is desired to know which of the poles of another needle or magnet is north. It is only necessary to approach the pole of the unknown needle to the north pole of the compass needle. If the compass needle be repelled, then the unknown magnet pole is north, or has the same polarity as that of the pole of the compass needle to which it has been approached. On the contrary, if the north pole of the compass needle be drawn or attracted to the approached pole of the unknown magnet, then the polarity of the unknown magnet is south, or opposite to that of the north pole of the compass needle, for it is unlike poles that attract each other.

It is not necessary to employ a compass needle in determining the polarity of unknown magnet poles. An ordinary bar magnet, placed on a piece of wood or cork and floated on the surface of water, will, as already stated, soon come to rest with its poles pointing approximately due north and south. Of course, as you can see, this floating magnet may take the place of a compass needle; for, when an unknown pole is brought into the neighbourhood of its north pole, you can at once tell that its polarity is north if the north pole of the floating magnet is driven away or repelled, and south if its north pole is drawn or attracted towards it.

It will interest you here to know that if a small, bright, and highly polished steel sewing needle is magnetised and slightly greased, by rubbing it with an exceedingly small

quantity of oil, or, indeed, by rubbing it with the fingers of the hand that generally contain a small quantity of oil, it will float on the surface of water provided it be carefully placed on it. Under these circumstances the floating needle will be far more sensitive than when supported on a piece of wood or cork. If you try this experiment you must not be disappointed if you do not succeed at first, since, unless the needle is placed very dexterously on the surface of the water, it will sink just as a piece of ordinary iron would. To be successful the needle must be highly polished and must be carefully placed on the water surface. I will not stop here to tell you why it is that a needle under these circumstances floats instead of sinks.

You are now able to understand what causes one end of a compass needle to point approximately to the earth's north. It is because the entire earth acts practically as one huge permanent magnet with its magnetic poles near its north and south geographical poles; that is, near the ends of the earth's axis. A compass needle, therefore, placed anywhere on the earth's surface, will point with its opposite poles towards the magnetic poles of the earth just as the compass needle when placed on the bar magnet represented in the preceding figure pointed with its poles towards the opposite poles of the bar magnet.

But a difficulty arises here as to the name that should be given to the end of the compass needle which points to the north of the earth. If one end of the compass needle points to the earth's north because of the attraction of the earth's magnetic pole, then this end must possess a polarity different from that of the earth's magnetic pole in the Northern Hemisphere. Now, if we call the end of the com-

pass needle that points to the earth's north the north pole of the compass, then the magnetism of the earth's Northern Hemisphere must be south; or, in other words, the south magnetic pole of the earth must be located in the earth's Northern Hemisphere, and its north magnetic pole in its Southern Hemisphere; while, if we call the magnetic pole in the earth's Northern Hemisphere its north magnetic pole, then the end of the compass needle which points, approximately, towards the earth's north, must be its south magnetic pole. This fact has given rise to considerable difficulty as to the proper names for the poles of the compass needle.

Various efforts have been made to avoid the confusion that has arisen from carelessness in naming the poles of the compass needle and the magnetic poles of the earth. Some have endeavoured to do this by calling the pole of the compass needle that points to the earth's north, the north-seeking pole, and the pole that points to the south, the south-seeking pole. This is all very good, but it does not remove the difficulty, since it simply states that the pole of the compass needle possesses such a polarity as would result in its seeking the north on account of the opposite magnetic attraction that is located at that point. It entirely leaves out the important question as to which is the true north pole, the north end of the compass needle, or the point on the earth near its geographical north pole.

Others have tried to distinguish the poles of the compass needle by calling them the red and the blue poles, the north-seeking pole being originally marked red, and the south-seeking pole blue, but as Sylvanus Thompson, in his excellent book, *Electricity and Magnetism*, remarks:

“ Here again, strangely enough, authorities differ, for in the collection of apparatus at the Royal Institution and the Royal School of Mines, the colours are used in exactly the opposite way to this.”

The French have solved this difficulty by calling the end of the needle that points to the earth's north, the south or austral pole, and the end that points to the earth's south, the boreal or north pole. Where books in the French language have been translated into English no little confusion is sometimes caused by this usage, especially when, as is sometimes done, translators properly translate the words “ austral magnetic pole ” as the “ south magnetic pole,” and the words “ boreal magnetic pole ” as the “ north magnetic pole,” while other translators increase the confusion by translating the words austral and boreal poles as north and south poles respectively.

You may sometimes have wondered why the north and south poles or ends of magnets are marked in some books by the letters *a* and *b*, or A and B, instead of the letters *n* and *s*, or N and S, that you will now see in most modern books. Of course, I need not tell you now that the letters *a* and *b*, and A and B, are contractions for austral and boreal.

I am glad to say that the practice now almost universally followed in all parts of the world is to give the name north magnetic pole to that end of the compass needle which points towards the earth's geographical north. In other words, it has been agreed to regard the Northern Hemisphere of the earth as possessing south magnetic polarity, and the Southern Hemisphere as possessing north magnetic polarity.

The action of the earth on a compass needle in causing it to come to rest when pointing approximately to the earth's north is that of a directive force only. Under the influence of the earth's directive force, a needle, when floating in a vessel of water, is merely swung around so that its north pole points approximately to the earth's north. It is not, however, drawn or attracted towards that

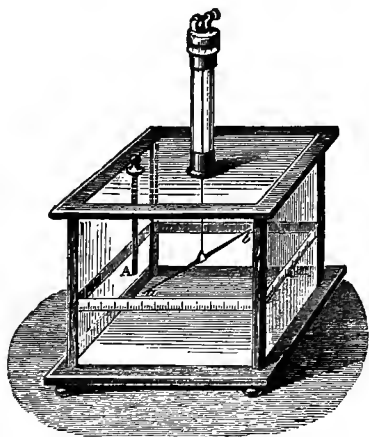


FIG. 13.—COULOMB'S MAGNETIC TORSION BALANCE

side of the vessel of water which lies nearest to the earth's geographical north. I will not attempt to explain the reason for this any further than to say that the compass needle is so small an object that its south end or pole is attracted or drawn towards that side of the vessel containing the water with practically as great a force as the other end is drawn towards the opposite side, so that there is, therefore, no motion of the needle to either side of the vessel.

The laws of magnetic attraction and repulsion were investigated by Coulomb, by means of a piece of apparatus known as the magnetic torsion balance. The general appearance and construction of this apparatus is represented in Fig. 13. It consists of a magnetic needle, *a b* suspended by a fine silver wire inside a cylindrical glass case, so that its ends or poles can come in the neighbourhood of another magnet that can be introduced inside the case in a vertical position through an opening in its top. The amount of force produced by the repulsion of the like magnet poles is measured by the amount the supporting silver wire must be twisted in order to move the horizontally suspended magnet a certain distance towards the pole of the vertical magnet. Without going any further into a description of this apparatus, it is enough to say Coulomb discovered that the force with which two magnets mutually repel or attract each other varies inversely as the square of the distance between them. That is to say, if at a certain distance, one magnet pole attracts or repels another magnet pole with a certain degree of force, then at a distance half as great, it will attract or repel it with a force four times as great.

CHAPTER VIII

MAGNETIC BLOWINGS AND SUCKINGS

I SUPPOSE nearly all of you have read the fairy story of "Fortunio and his Servants." Fortunio had obtained the services of seven men each of whom possessed in a remarkable degree some highly developed power. For example, one had such acute hearing that he could easily hear whispered conversation at a distance of many miles. Another had such an appetite that he could devour great mountains of food without, strange to say, appreciably increasing in bulk. Another could drink so much that he thought nothing of drying up all the springs and rivers in a given neighbourhood in a single day. Another could run so fast that he had never been beaten in a foot race. Another could shoot a gun so straight that he never missed, no matter how small the object might be, or how far off it was. Another possessed such strength that he could lift enormous weights as easily as if they were but straws, while the seventh and last could blow the air out of his lungs, so powerfully and skilfully as to produce a wind capable of throwing down buildings, or tearing up trees by the roots, at a distance of five or six miles from where he stood. But what was especially curious about Blower, the name of this servant, was that he could regulate the strength of these blasts or winds and so produce either furious storms or gentle zephyrs.

On the day Fortunio first met the last named servant,

he was passing with his other attendants through a part of the country where half a dozen windmills were whirling around with great rapidity. He was much surprised at this, since there was then no wind whatever except that turning the windmills.

"What makes the windmills turn?" Fortunio asked his companions.

"We don't know," was the reply. "Let us go on further; perhaps we will then see."

Sure enough, after they had gone on about five miles, they saw a man sitting on the ground blowing, as could be seen from the manner in which his cheeks were swelled out. He had covered his mouth with one hand except that he had left a little crack between two of his fingers.

"What are you doing, my good man?" inquired Fortunio. "Why have you so nearly closed your mouth with the hand you are holding over it?"

"I am driving a number of windmills five miles beyond," replied the man, pointing in the direction in which he was blowing, and which was in the same direction as that of the place at which Fortunio and his companions had seen the windmills furiously turning. "If I did not hold my hand in this way, my breath would turn the mills so rapidly that they would be broken to pieces and indeed the entire buildings would be blown away."

"Then come with me and my other servants," replied Fortunio. "They all possess wonderful powers. We will travel together through the wide world, and it will be strange if we do not become wealthy."

I would like to tell you the rest of this story about the clever things Fortunio was able to do by the aid of his

servants, but I must not take up too much time in a book that professes to tell only of the wonders of magnetism. During some of these exploits Fortunio discovered the great control his blowing servant Blower had over the strength of the winds he could raise in a moment. Blower found no difficulty whatever in causing winds to rage with such violence at distances of five or six miles from where he was, that sending an army against him was ridiculous, since he could easily blow it sky high into the air by a few puffs of his mouth. Moreover, he could so direct this wind that it could either disturb the surface for miles around, or the area it passed over could be limited so accurately that it could easily lift a man or a horse from the ground and hurl them into the air, without even ruffling the leaves of trees a foot or so from the place.

Possibly, some of you will say, although the story of Fortunio is interesting, it certainly has nothing whatever to do with The Wonder Book of Magnetism. I am sure that before I am through this chapter I will convince you of your mistake. Indeed, I can assure you that the story of Fortunio's blowing servant is closely connected with one of the most wonderful things that scientific men have recently discovered in connection with magnetism, and I have purposely told you the story because it cannot fail to impress this fact firmly on your minds.

You will remember that magnets possess the mysterious power of apparently acting at a distance; that, so far as can be seen, there is no medium connecting the magnet with the body on which it is acting. But somehow or other, say in the case of a compass needle, the invisible attendants of a magnet are able to see that it points ap-

proximately to the earth's north; in other words, that one magnet can so act on another, even at great distances, as to draw or attract it towards it and thus cause it to come to rest when pointing with one of its poles to the attracting magnet's opposite pole.

You will be surprised when I tell you that, according to the most modern ideas concerning the manner in which magnets are able to act at a distance, an extremely tenuous or practically weightless form of matter, formerly called an effluvium, is blown out its north pole into the space not only in its immediate neighbourhood, but even at considerable distances therefrom. In this respect then a magnet is able to do just what Fortunio's blowing servant could do; but, instead of doing this only occasionally, the magnet never rests, or never goes to sleep. Every day and night, year after year, it continues to blow out from its north pole this weightless matter which, after moving over various spaces in the neighbourhood of the magnet, finally re-enters it at its south pole.

The importance of this idea of a magnet acting at one end like a force pump to blow out magnetic effluvium, and at the other end like a suction pump, to draw it in again, will be understood when you know that it is solely to the presence of this effluvium, or, as it is more frequently called, of these magnetic streamings, that a magnet owes its power of drawing or attracting masses of soft iron to it, or attracting the opposite poles of other magnets, or of repelling or driving away their similar poles.

For convenience we will call this invisible matter, this weightless or imponderable effluvium, "magnetic streamings," or "magnetic flux," or simply magnetism. And

let us bear in mind the fact that it is imponderable or has no weight. I do not suppose you will be able to understand how any kind of matter can be absolutely without weight. Nevertheless, as far as any one knows, this kind of matter is weightless. We have been unable to discover that it possesses any weight. If matter at all, it is evidently a form that differs markedly from what we ordinarily call matter. By most, it is believed to consist of the universal ether.

Since magnetic flux is invisible we cannot tell in what direction it is moving, but I can assure you that there are good reasons for believing that magnetic streamings (or magnetic flux) are constantly passing out from one of the poles of every magnet with great rapidity and re-entering

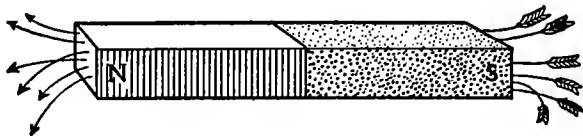


FIG. 14.—DIRECTION OF MAGNETIC STREAMINGS OF BAR MAGNET

the magnet at its opposite pole. It follows of course that, since magnetic flux is invisible, we cannot tell certainly whether it is leaving the magnet at its north pole and entering it at its south pole, or vice versa. But, simply as a matter of convenience, scientific men have agreed to regard the flux as leaving a magnet at its north pole, and returning, or re-entering it at its south pole.

In the case of a bar magnet, therefore, the direction of the magnetic streamings may be assumed to be as represented in Fig. 14, where the flux indicated by the heads

of the arrows, is represented as passing out of the magnet at its north pole and as having re-entered it at its south pole, as shown by the feathers of the arrows.

The power the fairy story claims was possessed by Fortunio's blowing servant was certainly remarkable, but I think you will agree with me that it could not begin to compare with the blowing power possessed by such a magnet as the earth; for, while Fortunio's servant could only cause the air blown from his mouth to travel over distances as great as five or six miles, yet the magnetic flux or streamings that are blown out from the north magnetic pole of the earth in the Southern Hemisphere, are able to reach half way round the earth or approximately 12,500 miles over its surface to the earth's south pole where, again passing into the earth, they rush through its mass and again escape at the north pole, thus keeping up a never-ceasing stream of magnetic whirlings or streamings that cause the many curious phenomena of the earth's magnetism.

Nor is the power of blowing out magnetic flux limited to the north magnetic pole of the earth. Every magnet, no matter what its size, even the minute fragment of lodestone already referred to that Sir Isaac Newton wore in a finger ring, blows out magnetic flux which for all we know extends possibly even for miles in the surrounding space in an almost ridiculously attenuated form. Do you not agree with me then that the story of Fortunio illustrates, in an admirable way, this most marvellous and mysterious ability of a magnet to act both as a force and as a suction pump?

Since the magnetic flux blown out of the north pole of

a magnet re-enters it at its south pole, and continuing through the mass of the magnet, again passes out of its north pole, it is evident that the path through which the flux passes is a closed path, or, as such a path is termed in science, a circuit. Now a circuit is not, as the word might indicate, a true circle. It is simply a closed path, or, in other words, if any part of the path be taken, a portion of the streamings that pass any point of the circuit at any moment will eventually return and again pass this point, and will continue doing this as long as the magnet remains a magnet. A circuit of this kind is called a magnetic circuit, just as the path or circuit through which electricity flows is called an electric circuit.

The strange power a magnet possesses of thus being able to produce magnetic streamings or flux that issue not unlike a wind from the north pole of the magnet, can, I think, be regarded as one of the greatest wonders of magnetism. That magnets possess such power has been suggested from very early times. For example, the same Lucretius, from whose writings we have already quoted, gives in his book, "*De Rerum Natura*," the following, which we quote from Busby's translation:

"Soon shall we trace by what mysterious laws,
 What secret energy, what latent cause,
 Steel, the strong magnet, actuates and draws.
 First, then, my loved illustrious Memnon, know
 Ceaseless effluvia from the magnet flow,—
 Effluvia, whose superior powers expel
 The air that lies between the stone and steel.
 A vacuum formed, the steely atoms fly

In a link'd train, and all the void supply;
While the whole ring to which the train is join'd,
The influence owns, and follows close behind."

As will be seen, the poet assumes that the magnetic effluvia drives out the air from the spaces between a magnet and a piece of iron or steel brought near it, thus producing a vacuum, and that it is the pressure of the air that forces the two bodies together. I wish especially to warn you that such an explanation cannot be accepted, since magnetic attractions and repulsions occur quite as well in vacua, or in spaces from which all the air has been removed, as they do in the air itself.

Although magnetic flux itself is invisible, yet the paths or circuits it takes in the space surrounding a magnet can be readily shown. Magnetic flux readily passes through various substances, especially through soft iron. If, therefore, a bar magnet be placed on the flat surface of a table, and a sheet of cardboard, or still better, a plate of window glass, be laid on the magnet, the magnetic streamings or flux readily pass through the glass or paper, so that if finely divided iron filings be passed through a sieve, so as to form a uniform and very thin layer on the upper surface of the plate, the streamings will pass through the separate particles of iron, and, if the plate or card be gently tapped, as by a lead pencil, the filings will arrange themselves as shown in Fig. 15. Here, as will be seen, the streamings pass out of one pole and in at the opposite pole, or, as we have assumed, they pass out of the north pole of the magnet and, after having traversed the space surrounding the magnet, re-enter at its south pole.

Of course, you will understand that in the above figure the direction of the magnetic streamings is only shown in a single plane; namely, in the direction of the horizontal sheet of paper. In reality, these streamings entirely surround the magnet. Their direction in other planes, however, can be shown in a similar manner by the use of iron filings. For example, if the bar magnet, instead of being laid horizontally on the table, is supported in a vertical

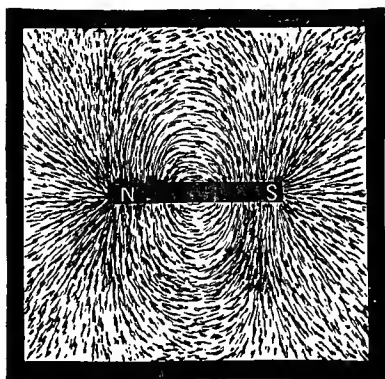


FIG. 15.—MAGNETIC FLUX OF BAR MAGNET

position, a glass plate placed horizontally over one of the poles, say the north pole, will, when sprinkled with iron filings and gently tapped, present the appearance represented in Fig. 16. Here, as can be seen, the streamings, issuing from the north pole, radiate, or pass off in all directions from the magnet poles in what appear to be straight lines.

The region of magnetic influence surrounding a magnet, through which the magnetic flux passes, is called a mag-

netic field. Let us now try to understand just what happens when the iron filings are scattered over the surface of the glass plate that is resting on a bar magnet. The magnetic flux in that portion of space that is occupied by the glass plate immediately passes through the small particles of iron, so that we can consider them as being strung like small beads on strings consisting of the stream lines of magnetic force. When the plate is gently tapped,

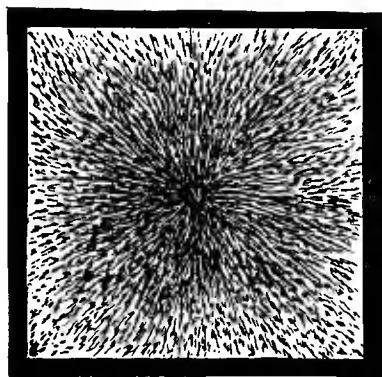


FIG. 16.—MAGNETIC FLUX FROM END OF BAR MAGNET

the filings arrange themselves in the directions of the stream lines; that is, in the directions in which the magnetic flux is passing, so that by looking at the tracks of the iron filings we can get an idea, although I grant only a rough idea, of the paths of the magnetic flux. In other words, the groupings, or arrangements of the iron filings, show the direction of the magnetic circuits in this particular part of the field.

Now when a compass needle is placed anywhere on the

earth's surface on its supporting point, the magnetic flux that is constantly being blown out from the earth's north pole and is passing over its surface into its south pole, endeavours to thread its way or pass through the needle. But it can only do this by entering the needle at its south pole and leaving it at its north pole. If, therefore, the compass needle is not pointing in the right direction, the magnetic streamings, like the invisible attendants in the palace of the white cat, gently push the needle around until they find the open door at the needle's south pole, and enter the palace of wonders; for I think by this time you will agree with me that a magnetic needle, or, indeed, any magnet, constitutes a veritable palace of wonders, a palace that we have only begun to explore.

CHAPTER IX

HOW MAGNETS PRODUCE OTHER MAGNETS IN THEIR NEIGHBOURHOOD

IF you thoroughly understand the preceding chapter as regards the story of Fortunio, you will see that a magnet is indeed a wonderful thing. It not only possesses the strange and mysterious property of directing a needle, as well as the power of attracting and repelling other magnets, but it appears to owe these powers to its ability to act as a force pump that blows magnetic flux out at its north pole, and as a suction pump that sucks it in again at its south pole.

You are now able to understand an important property possessed by magnetic flux called magnetic induction. Possibly this word is so strange that it frightens you. I confess that the word does sound difficult. Indeed, magnetic induction, as sometimes explained in books, is hard to understand, possibly too hard for young readers. I am sure, however, that it can be made easy, and I shall be surprised if, when it has been explained, you do not wonder how any one could think that magnetic induction could in any way be regarded as difficult.

If, as we have seen, a magnet is a compound blower and sucker—that is, a device both for blowing flux out from its north pole and sucking it in again at its south pole—then it necessarily follows that all magnets must have flux constantly passing through them; the north pole being

situated where the flux leaves the magnet, and the south pole where it enters it. In the same way, it follows that if magnetic flux is caused in any way to pass through a piece of magnetic substance, such as a piece of soft iron or steel, that as soon as the flux passes through the substance, it must acquire all the properties of a magnet, and must, moreover, retain these properties as long as the flux continues to pass through it. If it consists of hardened steel, it will retain its magnetic properties after it has been taken out of the field; but, if it consists of soft iron or soft steel, it will instantly lose these properties as soon as it is removed from the field.

Now magnetic induction consists in setting up or producing magnetism in substances by bringing them into a magnetic field in such a manner that the flux can pass through them. I'm sure there is nothing difficult about that. If the substance is magnetisable—that is, capable of being magnetised—it permits magnetic flux readily to pass through it. If, therefore, it is brought into a magnetic field, the flux of the field passes through it, and in doing so, magnetises it, or renders it magnetic. That part of the magnetisable substance where the flux enters becomes a south pole, and the part where it passes out, a north pole.

If you have followed this explanation you will see at once that, when a body is magnetised by induction, the polarity produced in the end of the body nearest the inducing magnet must be opposite to that of the magnet pole that causes it. If a bar of iron is brought near the north pole of a magnet, the flux coming out of the north pole will enter on the side of the bar that is nearest it,

thereby producing a south pole at this point; and, passing through the bar, will emerge at its opposite side where it will produce a north pole.

A similar thing will occur if the bar is brought so near the inducing pole as to come in actual contact with it. There will still be a south pole produced at the end touching the magnet, stronger, indeed, than when it was held at some distance from it. The presence of this south pole, however, will be entirely masked or hid by the opposite pole with which it has been brought into contact, so that the entire mass of soft iron seems to possess north polarity, or a polarity the same as that of the north pole with which it has been brought into contact. Indeed, it was at one time believed that the entire magnet thereby actually acquired north polarity. Magnetisation produced in this way was called "magnetisation by conduction." In point of fact, however, there is no difference between magnetisation by conduction and magnetisation by induction.

Now let us take the case of the iron filings spread over the surface of the glass plate that is resting on a bar magnet. The flux from the magnet readily passes through the glass, and threads also through the particles of soft iron, and magnetises them by induction. Wherever the flux enters the particles, they acquire south polarity. Wherever it leaves them, they acquire north polarity. The magnets so produced at once endeavour to swing around and move towards one another so that their north poles will come in contact with the south poles of the filings nearest them. They cannot do this very well owing to friction against the glass plate. When, however, the plate is gently tapped with a pencil, they are enabled so to

swing around that the particles are connected in long strings with their north and south poles in actual contact, so that they may be regarded as lines of magnetic flux with the iron filings strung on them like beads. This collection of filings, therefore, is an excellent example of magnetic induction.

Let us now carefully examine a few other cases where magnetism has been produced by induction. You will remember that the mere touching of a piece of iron or steel by a magnet pole will produce magnetism at the points touched. This is because the magnetic flux passes through the piece of touched iron or steel, producing in it a south or a north pole according to whether it passes into or out of the iron or steel at this point. Suppose we take the case of a bar magnet where a short cylinder of soft iron has been placed in contact with the north pole of the magnet. The flux blown out from this north pole, passing through the cylinder of iron, produces by induction a south pole where it enters, and a north pole where it passes out. It is on account of the opposite attractions of these north and south poles that the short cylinder of iron is attracted or drawn to and firmly held against the north pole of the magnet. Moreover, the magnetic flux passing out of the opposite end of the cylinder, which we will call 1, produces there a north pole, so that if a second cylinder of soft iron, 2, be placed in contact with the far end of 1, it will be held there. In the same way, other cylinders can be suspended from the north pole. As will be seen, this is just what the rings of soft iron did that Lucretius alluded to in his poem. Both of these are simple cases of magnetism produced by induction.

It is not necessary to bring the piece of soft iron into actual contact with the pole of the magnetising magnet. The same effect will be produced if a small air space exists between the two bodies. Suppose, for example, a bar magnet be placed on a support near a bar of soft iron. The magnetic flux blown out of the north pole enters the bar of soft iron, producing a south pole at the nearer end, and a north pole at the further end.

You are now also able to understand what it is that causes the filings to collect at the ends of a magnet, and why little or no filings occur at the central part; for, if you examine Fig. 15, which shows the collection of iron filings on the surface of the glass plate, you will see that, for the greater part, the flux is blown out at the north pole at one end, and enters mainly at the south pole at the other end, the space between being comparatively free from flux. This flux, streaming through the iron particles in the neighbourhood of the north and south poles, collects there in tufts or brush-like appendages, as shown.

You can also understand a very simple and yet interesting experiment in magnetism called the magnetic pendulum. If a small ball of soft iron is suspended from a silk, cotton, or any other thin thread, so as to be able to swing to-and-fro, and a magnet pole is brought near the ball, it is drawn or attracted to it, so that when the magnet is drawn away the ball will continue, for a while, to swing to-and-fro like a pendulum. The explanation is simple. The magnetic flux from the north pole of the magnet, entering the near side of the ball, produces a south pole at this point, and, under the attraction of the opposite

pole, the ball is drawn or attracted towards the pole of the magnet.

If the magnet be turned around so that its opposite pole is brought towards the suspended ball, the same phenomenon will be produced. The ball will be drawn towards the south pole. The reason is evident. Indeed, I will be surprised if you are not now able to explain this matter without my saying anything more about it; for you can see that the magnetic flux produced by the magnet has threaded through the opposite side of the suspended ball and, emerging from the side nearest the south pole, has produced at that end a north pole, and that as before these poles have mutually attracted each other. It is for this reason that a mass of soft iron or steel will always have produced in it, by magnetic induction, a pole of the opposite name to that which has been brought near it.

But the attraction produced by magnetic induction, in soft iron or steel, not only tends to draw or attract the soft iron or steel towards it, but is also itself attracted or drawn towards the soft iron or steel in which it has produced magnet poles. This can easily be demonstrated in the manner represented in Fig. 17, where a bar magnet, supported, as shown, by a thread, is held in the hand and brought near the north pole of a short bar of soft iron, supported on a stand. Under these circumstances the end of the magnet will be attracted or drawn towards the bar because of the opposite magnetic pole that has been produced by induction in the soft iron.

I think now you will have no difficulty in understanding what sometimes gives considerable trouble to young students in magnetism. Suppose we take a straight bar mag-

net and roll it in iron filings. The filings will collect unequally on different parts of the surface; for, if the magnet be taken out of the filings, and struck several sharp blows, few or no filings will remain at the centre of the bar, but will be found collected in greater quantities at the extremities or poles. Moreover, there will appear to be a gradual decrease in the quantity of filings from the extreme ends, where they are thickest, to the centre, where practically none have remained. In other words, the mag-

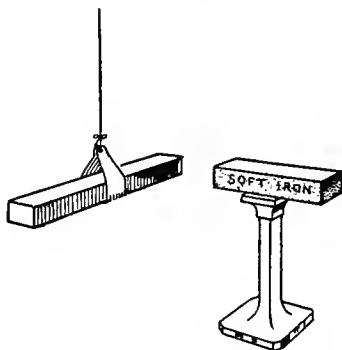


FIG. 17.—MAGNETIC INDUCTION

netic strength of the bar magnet is greatest at its extremities and gradually decreases towards its centre where the force is apparently entirely wanting. The ends, or places of greatest strength, are called the magnet poles, and the neutral point, midway between the poles, is called the magnetic equator. Moreover, if the polarity of these halves of the bar be tested, by bringing a small compass needle near the bar, there will be no trouble in showing that one-half of the bar possesses north polarity, and the other half south polarity.

It has frequently suggested itself to students of magnetism, on first learning this fact, that by suddenly cutting a bar magnet in two at its equator, there could readily be obtained what might be called a one-pole magnet; or, as it is sometimes called, a unipolar magnet. This, however, cannot be done. If you try it you will find that as soon as the bar is cut in half the cut ends possess magnetic poles quite as strong as the other ends.

If you care to do so, you can easily try this experiment; for, taking a strip of steel, say five or six inches in length, that has been cut from the main spring of a watch, and, magnetising it so as to bring its poles at the ends, you can convince yourself, by rolling it in iron filings, that the poles are situated at the ends, for here only do the filings collect.

If you now take a pair of metal shears and cut the piece of steel in halves you will find, on rolling the separate pieces in filings, that the cut ends possess poles that are quite as strong as those of the other ends; and you will find this to be true, even if you go on cutting the halves into quarters, the quarters into eighths, the eighths into sixteenths, etc. Indeed, no matter how far the subdivision is continued, the ends will exhibit strong magnetic opposite polarities.

It may seem to you that this is a very wonderful thing, but, as in other cases, the wonder ceases as soon as the matter is explained. It is clearly impossible to have a unipolar magnet, for a magnet cannot exist unless flux is passing through it. To do this, flux must pass in at one end and pass out at the other end, so that, no matter how small a magnet may be, the point where the flux enters

must possess south magnetic polarity and the point where it passes out, north magnetic polarity.

The reason a bar magnet only shows two free poles at its extremities, although it consists of a great number of separate magnets with their opposite poles in contact, is because the opposite poles neutralise or mask each other completely at the centre, where there are an equal number of opposite poles, and less thoroughly towards the ends.

The fact that a magnet may consist of a great number of separate magnets can be shown by an experiment suggested by De Haldat, who partially filled a brass or glass tube with hardened steel filings, and then thoroughly magnetised the mass so as to produce north and south poles respectively at the ends of the tube. Now such a magnet clearly consists of as many separate magnets as there are particles of steel filings, but these separate magnets are so connected at their opposite poles that it is only at the extremities of the tube that there is any marked free polarity; and at the equator of the magnet, or at the point midway between the two poles, there is no free polarity whatever. That the free poles at the ends are due to the alignment of the steel filings—that is to their being arranged in many parallel chains with their opposite poles in contact—is easily proved by thoroughly shaking the tube. This breaks the alignment and thus rapidly decreases the polarity, until at last, when the mixing is complete, the tube has almost entirely lost its magnetisation.

Since the earth acts like a single huge magnet, you can now easily understand how it is that such substances as lodestones are magnetised by magnetic induction from the earth. If the magnetic flux blown out from the north pole

of the earth while on its way to the south pole passes through masses of hard magnetic oxide of iron, it will produce south poles at the points where it enters and north poles where it passes out of them; so that there is nothing strange whatever about specimens of lodestone or the magnetic oxide of iron being permanently magnetised.

In the same way we can understand how masses of hardened iron or steel may become permanently magnetised by remaining for a long time in contact with the earth, since, as I think you can see, such bars would best be magnetised by the earth's flux passing through their greatest length. Now, as the earth's flux, while passing from the north to the south pole, generally flows or moves in a north and south direction, the iron bars in contact with the earth are more apt to be magnetised if they extend in these north and south directions. I have taken the following examples of magnets produced in this way by induction from the earth from a book called "Hutton's Researches in Science," published in 1851. I am sure they will interest you.

One of these cases, an iron bar that had remained for many years in a window frame extending north and south, was found, when removed from the frame, to be strongly magnetised.

"It has been observed," says Hutton, "that a bar of iron, kept for a long time in the direction of the meridian, or in a situation nearly approaching to it, acquires the magnetic virtue. The steeple of Notre Dame de Chartres having been considerably damaged by a great storm in 1690, some bars of iron taken from it were found to be magnetic. But what is still more remarkable, pieces of these bars,

which were almost destroyed by rust, formed excellent magnets. The Abbe de Vallemont wrote at that time an account of them, which was published in 1692."

Hutton also relates the following somewhat similar case:

"Gilbert, an English physician and philosopher, who wrote a treatise on the magnet, had then observed that the small bars of an iron window frame, placed north and south, which had remained many years in the same position, were become magnetic. He relates also, that the wind having bent an iron bar which supported an ornament on the church of St. Augustine, at Rimini, when the monks belonging to it were desirous, ten years after, to straighten this bar, they were much surprised to find that it possessed all the properties of a good magnet. Muschenbroek speaks of a similar circumstance in regard to some pieces of iron taken from the tower of Delft. We read also in the Memoirs of the Academy of Sciences for the year 1731, that there was at Marseilles a bell which moved on an iron axis, standing in an east and west direction, and resting with two ends on stone; that the rust of these ends mixing with the dust rubbed from the stone, and with the oil used to facilitate its motion, formed together a hard and heavy mass, which, when detached, was found to possess all the properties of the magnet. It is believed that this bell had existed in that situation 400 years."

A somewhat similar instance is often found in the case of the bars of the iron railings that were formerly so commonly employed around churches and other buildings in the streets of large cities. The ends of these bars are frequently found to be strongly magnetised by contact with

the earth; or, more correctly, by induction from the earth's magnetism.

Hutton also cites the following interesting cases:

“Gilbert observes also, that if a bar of iron placed north and south be brought to a red heat in a forge, and be then beat on the anvil in the same position, it will acquire the magnetic virtue; and that if this virtue be not immediately sensible, it will become so by repeating the operation. But it is to be observed that for this purpose the length of the iron bar must be 100 or 150 times its diameter. The case is the same with a bar of iron if it be heated and then cooled in the direction of the meridian.”

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CORNELL UNIVERSITY.

CHAPTER X

MAGNETIC PATHS OR ROADS

REGARDING a magnet as a combined force and suction pump, a magnetic circuit may be defined as the path the magnetic flux takes when, blown out of the magnet at its north pole, it passes through the outside space, re-enters it at its south pole, and, after passing through the magnet, again comes out at its north pole. During that part of its path which lies outside the magnet, the flux may pass through various devices that it operates, either by reason of its directive tendency, or by virtue of its powers of attraction or repulsion.

All magnetic circuits consist of three parts: a magnetic source or magnet for producing the flux; a receptive device, such as an armature, operated by the flux passing through it; a circuit or path through which the flux passes, in general consisting, outside of the magnet, of an air space that may contain here and there masses of iron or steel. Within the body of the magnet, the path consists of the iron or steel of which the magnet is formed.

The quantity of flux passing through a magnetic circuit varies with the strength of the magnet; or, in other words, with the strength of the magneto-motive force, or the force that blows the flux out of the magnet at its north pole, and sucks it in again at its south pole. Since the phrase magneto-motive force is rather long, and is, moreover, frequently employed in magnetism, it is generally contracted

as M. M. F. When, therefore, you see the letters M. M. F. you will know what they mean.

It can be shown that the quantity of magnetic flux passing through any circuit increases directly with the strength of the M. M. F. If a certain M. M. F. produces a given quantity of magnetic flux, twice as great an M. M. F. will produce twice as much magnetic flux. The quantity of magnetic flux passing in any circuit also depends on the resistance the different portions of the circuit offer to the passage of the flux. This resistance is sometimes called the "magnetic resistance," although among scientific men it is more frequently known as the "magnetic reluctance." In soft iron the magnetic reluctance is very small. It is somewhat greater in hard steel, and is much greater in air. Therefore, when a large portion of any magnetic circuit consists of air, unless the M. M. F. is comparatively great, the quantity of flux that passes is necessarily small.

I think you will have no difficulty in understanding that the magnetic resistance or reluctance of a straight bar magnet is necessarily greater than the resistance of a bar of the same dimensions, when bent either into the form of a U-shaped magnet or a horseshoe magnet. Moreover, if, as is often the case, the horseshoe magnet has its opposite poles brought nearer together than they are in the case of a U-shaped magnet, the reluctance of a horseshoe magnet of equal length, breadth and depth will be smaller than that of a U-shaped one.

Since, too, anything that decreases the length of the air gap or air space between the poles of a magnet necessarily decreases its magnetic reluctance, you can understand how an armature of soft iron placed in contact with the poles

of a magnet will decrease its reluctance and thus increase the amount of flux that passes through its circuit; for soft iron possesses a resistance or reluctance that is much less than that of air. I do not, however, wish you to suppose that this is the only reason for the increase in the magnetic flux passing through a circuit whose air space has been bridged by a mass of soft iron. There is another reason,

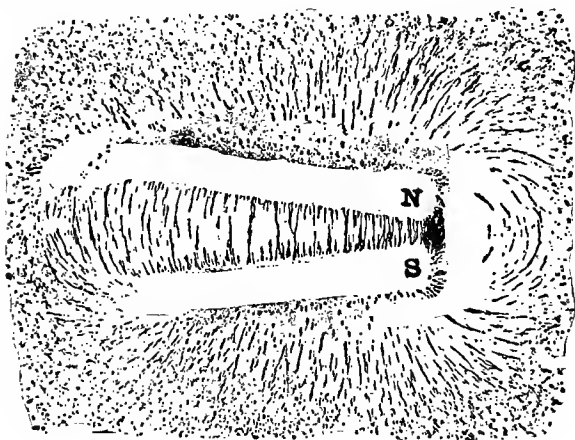


FIG. 18.—FLUX PATHS OF HORSESHOE MAGNET

and indeed the principal reason for this increase, which will be fully explained in a subsequent chapter.

Care must be taken in the examination of the figures of the magnetic flux paths, already represented, to remember that such figures are of value only for showing the direction in which the flux passes. They are almost worthless for showing the amount of the flux that passes. At least this is generally true. Take, for example, the flux paths of the horseshoe magnet represented in Fig. 18. As is al-

ways the case with such collections of filings, the flux paths are shown only in those portions of the magnetic circuit that lie outside of the magnet. Within the magnet itself those lines are of course invisible. Now, in the above figure, the greatest quantity of flux, in the space outside the magnet, passes through the air gap between the poles. Consequently, the greatest amount of iron filings should have collected in this space. If you examine the above figure, however, you will see that, so far from this being the case, there is a gap in the space in front of the poles that contains no filings whatever. This is because the iron filings, that originally collected in this space, slid over the smooth surface of the glass at the tapping of the glass plate and collected in larger quantities between the poles.

One might suppose the amount of filings seen in the space outside the legs of the magnet indicates that as much magnetic flux existed here as between the legs. This conclusion, however, would be erroneous; for, as an examination will show, a large proportion of the particles outside the legs is not arranged in lines, while all the iron filings between the legs are so arranged.

There is another point that can be illustrated by the flux paths of the preceding figure. A distinction is sometimes drawn between what is called "useful flux" and "useless" or "stray flux." In the case of a permanent horseshoe magnet, when employed only for the attraction of its armature, only the flux that passes through the armature is able to do useful work. All other flux must be stray or useless flux. You can understand, then, what is meant by "magnetic leakage." It is the name given to the stray or useless flux that is unable to do the work re-

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quired because, having leaked or passed out of the path that has been intentionally provided for it, it fails to pass through the armature.

The groups of iron filings, such as shown in the above figure, are sometimes called "magnetic figures." It is possible, by their study, to obtain excellent ideas not only of the paths of the magnetic flux but also of the manner in which oppositely directed flux streams attract one another, and similarly directed flux streams repel one another.

Before doing this, however, it may be interesting to tell you how the magnetic or flux figures above referred to are obtained. I am the more willing to do this because it will show you how to perform some simple experiments in magnetism that are beautiful, and cannot fail to impress thoroughly on your minds certain important facts.

If you have been careful in obtaining magnetic figures with iron filings on a glass plate, you will find these groupings so beautiful that I am sure you would like to obtain good photographs of them. Now you can easily do this in the following manner. If, instead of employing a clean plate of glass on which to collect the filings, you employ a glass plate that has been thinly covered with wax, it is easy to fix the filings in place by heating them in any manner that will cause them to sink into the wax without altering their positions as regards one another.

In order to coat a plate of glass on one side uniformly with a thin layer of wax, it is only necessary to heat the plate and then rub a cake of white wax over one of its surfaces. The plate must be hot enough to melt the wax readily. Within certain limits, you will get better results the smaller the quantity of wax that is spread over the

plate. It is necessary, however, that you cover the entire surface. As soon as this is done, in order to remove the superfluous wax from the plate (for you are almost sure to use too much wax in covering it), place a soup plate or a meat dish on a stove, and rest the glass plate on it in an inclined position with the wax surface uppermost. The glass plate will rapidly heat and the melted wax will drain off its surface leaving a thin coating uniformly covering it. The plate is then removed from the stove and permitted to cool, when a hard, uniform and thin surface or coating will remain on one side of its surfaces.

Now placing the wax-covered plate over the magnet, with its wax surface uppermost, a grouping of iron filings is obtained in the manner already explained, and it only remains to fix them in place on the plate. This is easily done by holding a heated smoothing iron or flatiron, such as is used for ironing clothes, a short distance above the plate, being careful not to touch it. The heat is rapidly imparted to the filings, which soon sink into the wax coating to which they are firmly held on the removal of the smoothing iron, as the wax hardens.

If the glass plate, with its fixed filings, is now placed, with the filing side upward, over a sheet of the blue paper employed for obtaining blue prints of drawings, and is exposed to the sunlight, a photographic negative will be obtained of the filings. This is called a negative because the portions of the paper that are affected by the light, instead of being the spaces on which the filings have collected, will be the uncovered spaces between the filings, while the filings themselves will be represented by white spaces. The light being unable to pass through the filings

leaves the paper unaffected, but colours the uncovered portions. Photographic negatives so obtained are very beautiful, and give one an excellent idea of the shapes of the groupings.

A much better method for obtaining magnetic pictures photographically, a method, moreover, that produces photographic positives, is so simple that I trust you will, if possible, try it. For this purpose you will need a dark

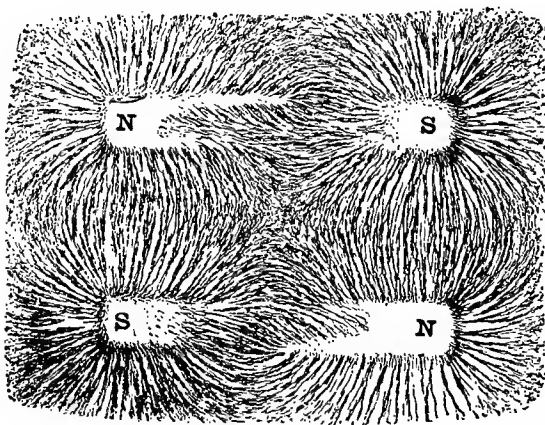


FIG. 19.—FLUX PATHS OF BAR MAGNETS, OPPOSITE POLES FACING

photographic room. If you have no such room yourself you can try the experiment at night, but it is much better to use the dark room. I am sure that any of your friends, especially your older friends, would permit you to use their dark room for this purpose, if you can convince them that you are careful.

If you have obtained the use of a room you must first see that no light enters except that which comes through

the red glass plate in the window near the developing trough. Now placing the magnet, whose flux paths you wish to photograph, on a perfectly flat or horizontal surface, rest on it, also in a horizontal position, a rapid photographic dry plate, with its sensitive side upwards. In this, as in all experiments with magnetic fields, it is essential that the plate be perfectly level or horizontal. If it is even

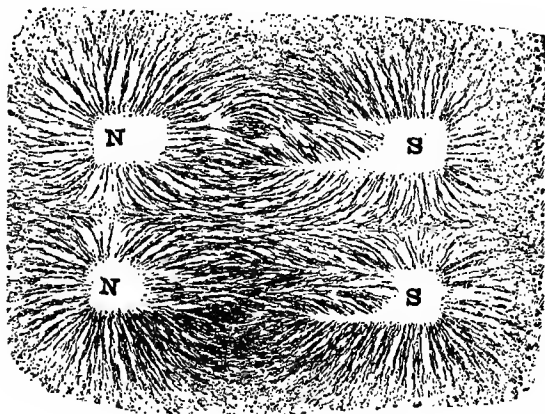


FIG. 20.—FLUX PATHS OF BAR MAGNETS, SIMILAR POLES FACING slightly tilted, the filings will collect in greater quantities towards the lower edge, thus spoiling the groupings.

Dusting the finely divided filings over the sensitive surface of the plate, tap it as before. As soon as a satisfactory grouping has been obtained, strike a match, and, holding it four or five feet above the plate, permit it to burn for a small fraction of a second, and then extinguish it. You understand what will have happened. The light has acted on the sensitised surface of the plate wherever it has fallen. Immediately under the particles of iron filings the plate

has been left unaffected, but in the spaces between the filings the light has been able to act on its surface.

The iron filings are now removed from the photographic plate, and the plate is thoroughly washed by holding it under the water tap. It is then developed and fixed, when it will be found to contain an excellent negative of the groupings; that is, all the parts covered with iron filings

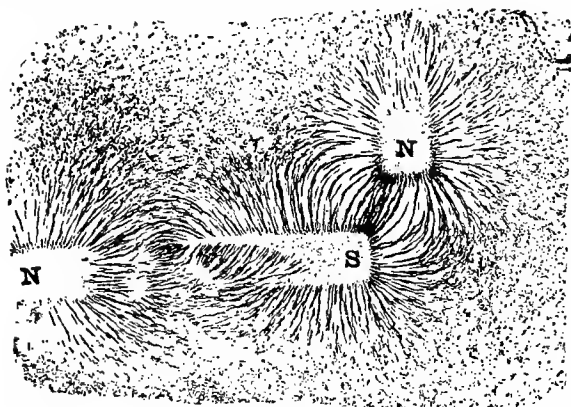


FIG. 21.—FLUX PATHS OF BAR MAGNETS, OPPOSITE POLES AT RIGHT ANGLES

have been left unaffected, and all the uncovered or clear parts have been darkened by the action of the light.

If this negative is employed in connection with a sheet of blue print paper, or still better with a sheet of solio paper, or indeed with any kind of photographic printing paper, a beautiful photographic positive will be produced which accurately represents the groupings.

Now that you understand how these pictures are taken, let us carefully examine some of them in order to see what

they can tell us. This examination will repay you since, when intelligently observed, such photographs are capable of giving no little instruction.

To begin with, let us take the photograph of the flux streams of the two straight bar magnets represented in Fig. 19. I have marked on the ends of the bar magnets in these photographs the letters N and S, so that you

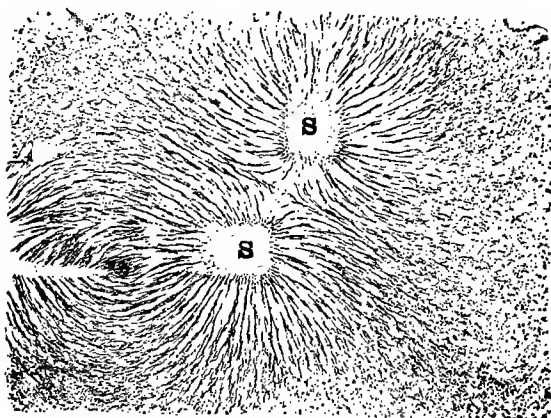


FIG. 22.—NEUTRALISED FLUX STREAMS

can see their polarity. The magnets have been placed parallel, with their opposite poles facing each other.

The paths of the flux streams that were blown out from the north pole are clearly indicated. You can see, too, the paths the flux has taken in order to enter the south poles of the magnets. You can also see a peculiar region situated in the space midway between the two magnets and between their north and south poles, in which the flux has taken the curiously curved paths shown.

Let us next examine the flux paths of the same two bar

magnets when placed parallel, but with their similar poles facing each other, as is represented in Fig. 20. Here you can readily see between the similar poles, as, for example, between the two north poles, that the opposing streams have neutralised or quenched each other's motion, producing an almost straight line of no motion, or what, if these were streams of water, would correspond to the line of slack water. A similar line also exists between the two opposed south poles.

In Fig. 21 two dissimilar poles of the same two bar magnets are placed at right angles, as shown. Here the direct passage of the magnetic flux from the north pole into the south pole is clearly indicated.

In a similar manner you will see in Fig. 22 the line of no motion where the flux streams from the two south poles, placed at right angles to each other, have neutralised or quenched each other's motion.

While, as has already been described, it is impossible to have a magnet with a single pole only, since all magnets must necessarily possess two poles, one where the flux enters and the other where it leaves the magnet, it is apparently possible to have what looks like a magnet with an odd number of poles, for example, with three, five, or seven poles. Now, from what has been said, it should be as impossible for a magnet that possesses more than two poles to possess any odd number of poles, as it should be to have a magnet possess a single pole only. A magnet may have two, four, six or eight poles, but it cannot possibly have three, five or seven. Consequently, magnets that seem to possess an odd number of poles are sometimes called anomalous or abnormal magnets. I am glad to say that

there is nothing abnormal about such magnets. A magnet that apparently possesses three poles in reality possesses four; while a magnet that apparently possesses four poles in reality possesses six, and so with any other number.

If you examine Fig. 23 you will understand this matter. Here a straight bar magnet that has been rolled in iron filings shows the characteristic tufted appearance at three portions of the bar; namely, at its two ends and in the middle. One might say carelessly, therefore, that this is a three-pole magnet. Now, in reality, as you will see if you carefully examine the above figure, while the extreme

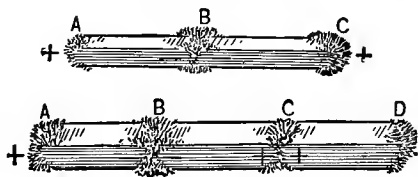


FIG. 23.—ANOMALOUS MAGNETS

ends of such a bar possess north polarity, the middle of the bar possesses south polarity, because there are two south poles that touch each other at this point. The bar, therefore, has four poles.

In the same figure there is a straight bar magnet in which four magnetic tufts of iron filings have collected when the magnet was rolled in iron filings. In this case, however, the free extremities of the bar possess north and south polarity respectively, while the two intermediate poles consist, as shown, of two opposed south poles and two opposed north poles. The magnet, therefore, possesses six poles.

Since the name "anomalous magnet" is also given to another kind of magnet, it is, I think, better to call the apparently single poles, that seem to exist where two poles of the same name come together, "consequent poles" and the magnets "consequent magnets."

As we shall see in "The Wonder Book of Electricity," the field magnets of dynamo-electric machines often consist of the consequent poles of electro-magnets.

CHAPTER XI

WHAT OERSTED DISCOVERED

TOWARDS the end of the year 1819, Hans Christian Oersted, a professor in the University of Copenhagen, discovered an entirely new way of magnetising iron or steel that produced magnets not only stronger than ever before, but also produced them much more easily.

Oersted made this discovery while he was trying to see if some relation did not exist between electricity and magnetism. Nearly twenty years before this time, Alexander Volta, Professor of Natural Philosophy in the University of Pavia, Italy, had made his great invention of the voltaic battery, a device for producing electricity by chemical action. Scientific men had long suspected that a close relation existed between electricity and magnetism, but they had been unable to find just what this relation was until 1819, when Oersted discovered it.

What Oersted did was simply this. Closing the circuit of a voltaic battery, so that its electricity could flow through a conducting path provided for it, in this case a copper wire connected with the terminals of the battery, he held this wire above and parallel to a compass needle that had come to rest pointing, approximately, towards the earth's geographical north. What Oersted discovered was that, by reason of the electric current flowing through it, the conductor had become a magnet and therefore caused the needle to move out of its north and south direction.

A modification of the simple apparatus Oersted employed in this great experiment is shown in Fig. 24. When the electric current from the voltaic battery was permitted to flow through a conducting wire placed above and parallel to a magnetic needle that had come to rest pointing, approximately, to the earth's north, Oersted found that the wire acted as a magnet and turned the needle out of its north and south direction. When the current was flowing through the copper wire in the direction indicated by the arrows, the needle was deflected in the direction shown. If,

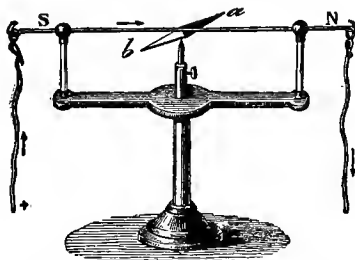


FIG. 24.—OERSTED'S APPARATUS

however, the current through the copper wire was caused to flow in the opposite direction, the needle was deflected in a direction opposite to that shown in the figure.

On first reading this account of Oersted's discovery it may seem to you that it could not be of much importance to science, but when I tell you the many things that came from it you will not be surprised to learn that it caused the greatest excitement everywhere, especially among scientific men, so that in all parts of the world almost everyone who could get a compass needle and a voltaic battery soon was showing to all his friends, and indeed to all who would

visit him, the curious behaviour of a wire carrying an electric current when held near a compass needle at rest.

Among other scientific men who repeated these experiments was Sir Humphrey Davy, the great English chemist. This was the same Davy who discovered the new elements potassium, sodium, etc. Davy regarded the discovery of Oersted's of such value that he read a paper describing it to the Royal Society of London on the 16th of November, 1820.

Oersted's discovery may be stated as follows:

When an electric current flows through a conductor, magnetic flux is produced that makes the conductor a magnet. In other words, an active conductor, that is, a conductor through which an electric current is flowing, becomes a magnetic blower and sucker. In this case, however, the magnetic flux does not come from the mass of the conductor itself, but from a portion of space in the air, or other medium, surrounding the conductor. These magnetic properties of the conductor are acquired as soon as the current begins to flow and are lost as soon as it ceases to flow.

It makes no difference what may be the kind of material through which the electric current is flowing; it may be copper, gold, silver, or lead; it may be a part of the human body; it may consist of liquid substances such as acid solutions, or it may even be a portion of empty or vacuous space. But as soon as the current passes, the conductor at once acquires the properties of a magnet, and has magnetic flux or magnetic streamings set up that move around it in planes at right angles to the direction in which the current is flowing.

Now I am afraid that the expression, "in planes at right angles to the direction in which the current is flowing," although simple from a scientific standpoint, since it expresses exactly the idea intended to be conveyed, may not be clear to you. Let me, therefore, see if I cannot make it clearer.

Probably the difficulty you have in understanding the expression arises from the fact that it contains two words which, though simple enough in themselves, sound odd to

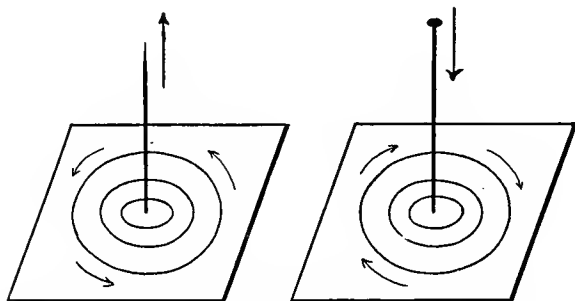


FIG. 25.—FLUX MOVING AT RIGHT ANGLES TO CURRENT

you because you have seldom used them. They are simple enough, however, when you understand them, as, indeed, is true of everything.

Suppose we approach this matter from another standpoint. Stick a pin through the middle of a card so that the pin's head is brought close against the lower surface of the card. Then rest the card with the head downwards on the top of a table, being careful to see that the pin points straight up towards the ceiling. Now regard

the pin as a part of the path of the electric current, and think of this electric current as flowing from the head of the pin towards the point; that is, from the floor of the room towards the ceiling. Then the pin represents the axis of this part of the electric circuit, or a straight line extending in a direction in which this portion of the circuit is flowing, and the card represents a plane or flat surface at right angles to the axis. If now with a pair of compasses, or in any other way, you draw circular lines around the pin these lines will represent the paths of the circular flux that is produced by an electric current, when

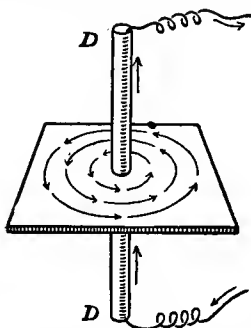


FIG. 26.—FURTHER ILLUSTRATIVE OF FIG. 25

it flows through the pin, as represented in Fig. 25. Be careful that these lines do not pass anywhere through the pin, but are everywhere equi-distant from it; that is, that they form concentric circles or circles that have a common centre.

The direction in which the circular flux produced by an electric current flows depends on a direction in which the electricity flows. If the electricity flows as in the above figure, from the head to the point of the pin, or comes out

of the card from below upwards, the flux will have a direction contrary to that of the hands of a watch or clock, or, as is commonly called, counter-clockwise. Or it will be in the direction it would be necessary to turn a screw in order to move it in the direction in which the current is flowing. If the current flows from above downwards, then the direction of the circular flux will be the same as that of the hands of a watch or clock, or clockwise.

I am so desirous that you shall thoroughly understand this that I will ask you to examine Fig. 26 closely. Here DD represents a short piece of the copper wire through which the current is passing in the direction indicated by the straight arrow. The wire DD passes through the centre of a stiff card or flat plate. As you will see, DD points straight up and down, or is vertical to the horizontal plate. Now, when the current flows from below upwards, as indicated, magnetic flux produced in the concentric circles flows in the direction indicated by the curved arrow heads, or in a direction opposite to that of the hands of a clock or watch.

If you have carefully examined the above figure you cannot make the mistake that is sometimes made by those first studying this matter. The circular flux produced by the electric current flows in paths that are circular, and not spiral, that is to say, these paths are not as represented in the lower half of Fig. 27, but as in the upper figure.

They do not consist of a single line of magnetic flux bent on itself in a spiral as shown in the lower half of Fig. 27, but of a number of separate lines, each of which extends in a complete circular path, while beyond these are a number of larger flux circles, and beyond these still larger cir-

cles, etc., all, however, having as a common centre the place where the conductor extends through the coil.

The amount of circular flux produced depends upon the quantity of electricity that is flowing through the wire, or, as we say in electricity, it depends on the strength of the electric current. If the current strength flowing through the conductor is increased, the quantity of circular flux is increased. It does not seem, however, that this increase consists in making these circles thicker, but in producing

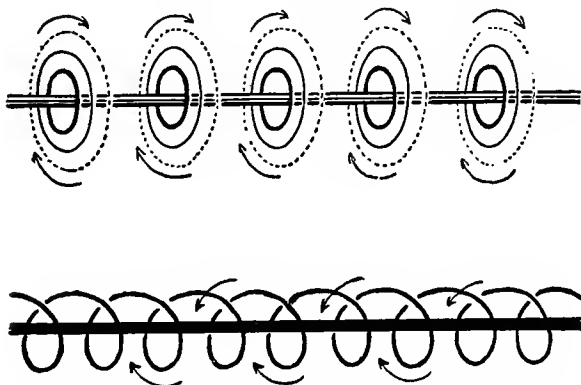


FIG. 27.—TRUE AND FALSE DIRECTION OF CIRCULAR FLUX

a greater number of them. When the current strength increases, the lines of circular flux spread outwards in all directions around the conductor, thus reaching a greater distance from it, while, when the current strength decreases, they contract or move inwards towards the conductor. I wish you to remember this fact because we shall use it in a subsequent chapter when we describe how Michael Faraday made a great discovery, a discovery that

was just the reverse of the Oersted discovery; for, as we have stated, what Oersted discovered was how electricity can be made to produce magnetism, while Faraday found out how magnetism could be made to produce electricity.

Of course, you will understand that, while I have represented the conductor through which the current is flowing as occupying a vertical position, and the card as occupying a horizontal position, an electric conductor will have circular lines of flux produced around it, no matter what may be its position. It may be vertical or horizontal, or inclined in any direction between the vertical and the horizontal, but when the circular flux is produced it is always produced in a plane at right angles to the axis of the wire. And now I trust these words "in a plane at right angles to the axis of the wire" no longer hide from you the idea it is intended they shall convey.

If you have thoroughly grasped the above idea, you will understand that the phenomena of an electric current and magnetism are so closely bound together that it is impossible to separate them. It is absolutely impossible for an electric current to flow in any direction through a conductor without having circular lines of magnetic flux set up around it in concentric circles in planes at right angles to the axis of that conductor. In other words, an electric discharge necessarily produces magnetism, and this is true whether the discharge is from a voltaic battery, whether it is from the dynamos that are producing electricity for arc and incandescent lamps, from the generators that are producing the electricity for moving trolley cars, or whether it be a lightning flash passing between the clouds and the earth.

Remembering what has been said about magnetic induction; *i. e.*, that when magnetisable substances such as soft iron or soft steel filings are brought into a magnetic field, so that the magnetic flux can thread or pass through them, there is necessarily produced a south magnetic pole where the flux enters the filings, and a north magnetic pole where it leaves them, you can understand that if iron filings are scattered over the surface of the glass plate or card represented in the preceding figures, and the plate or card

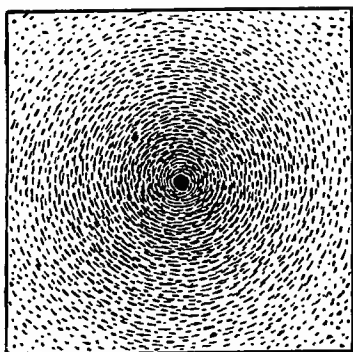


FIG. 28.—MAGNETIC FLUX PATHS PRODUCED BY CONDUCTING WIRE

be gently tapped, they will be arranged in the directions of the circular flux paths.

It is in this way that the magnetic figure or magnetic field represented in Fig. 28, surrounding a conducting wire through which a current is flowing, has been obtained. The dark circle in the centre shows the place where the conductor is passing through the centre of the plate, while the concentric circles surrounding the conductor consist of masses of magnetised iron filings that have arranged

themselves in closed paths with their north and south poles in contact when the plate was gently tapped.

You can now also understand from the examination of Fig. 26, already referred to, what would happen if a magnetic needle were brought near the conductor DD, for of course the lines of circular flux are produced along the entire length of the active conductor. No matter, therefore, where the needle is placed, provided it is placed near the active conductor, there will happen to it just what happens to a compass needle placed in the earth's magnetic field. The unseen attendants; *i. e.*, the magnetic flux, will gently push the needle around until the flux enters at its south pole and comes out at its north pole. As soon as the needle gets in this position, it will come to rest.

Or, putting this matter in another way, a magnetic needle if brought near an active conductor comes to rest when it points in the direction in which the flux is moving, and, since direction around a circle is constantly changing, the compass needle must of course take up different positions on different sides of an active conductor.

Scientific men were quick to see the many important properties possessed by active conductors, by reason of their power of changing the position of a compass needle. If a small magnetic needle, NS, be placed as shown in the centre of the rectangle, Fig. 29, each portion of the circuit will act so as to deflect

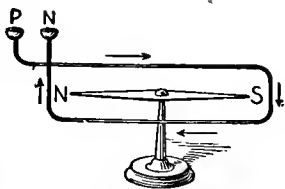


FIG. 29.—DEFLECTION OF NEEDLE BY ACTIVE CONDUCTOR

it in the same direction. Shortly after the announcement of Oersted's discovery, Schweigger, a German physicist, showed that if an insulated conducting wire were bent into the form of a hollow rectangle with many turns, the power of the conductor to deflect a magnetic needle would be greatly increased or multiplied.

The form generally given to Schweigger's multiplier, as the device was called, is shown in Fig. 30. Here, as can be seen, the needle is placed at the centre of a rectangle that consists of many turns of insulated wire, so that the deflecting power of the circuit is greatly multiplied.

A variety of electrical instruments depend for their

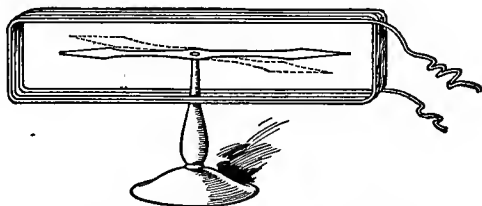


FIG. 30.—SCHWEIGGER'S MULTIPLIER

operation on this principle. These instruments are called galvanometers, voltmeters, and ammeters, and are employed in the measurement of electricity.

Ampère, who may fairly be regarded, at this time, as one of the foremost of French physicists, almost immediately after hearing of Oersted's discovery, began an extended series of investigations, and was soon able to demonstrate that not only was an active conductor able to deflect a compass needle, but that a compass needle or magnet was able to deflect an active conductor, and, moreover, that an active conductor, suitably coiled and supported, possessed

directive powers like a compass needle, and had poles at its ends, like those of a compass needle or a bar magnet.

Ampère made many curious experiments among which were the following: In order to show how one active conductor was able to attract or repel another conductor according to the directions in which the current was flowing, he arranged matters so that one of the conductors was fixed and the other movable, as represented in Fig. 31.

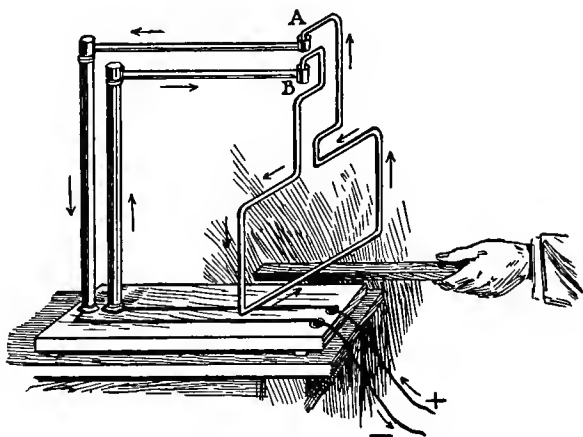


FIG. 31.—AMPERE'S EXPERIMENT

Here two metallic pillars, connected respectively at + and — with the positive and negative poles of an electric source, were placed, as shown, on a stand. Horizontal arms, attached to the top of these poles, were provided with agate suspension cups, in which were placed a few drops of mercury. The conducting wire, bent in the form of a rectangle, A, has its upper extremities provided with points, so that, when dipped in the mercury cups, they are not only

suspended so as to be free to move, but readily permit the electricity to flow through the circuit. In this manner the conducting rectangle is suspended at the extremities of the pillars so as to be free to turn. Now when a current of electricity flows through this circuit, the streams of circular magnetic flux that are produced around both the fixed and movable conductors act on each other magnetically and cause the movable conductor to be deflected.

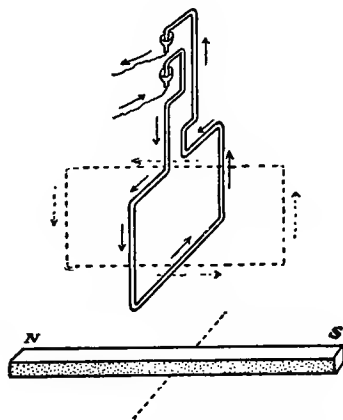


FIG. 32.—AMPÈRE'S EXPERIMENT

In order to show the action of a magnet on a movable conductor, the following apparatus was used. A movable rectangle was placed over a straight bar magnet, NS, with its plane parallel to the plane of the bar magnet as represented in Fig. 32 by the dotted line. As soon as an electric current was caused to flow through the rectangle in the direction of the arrows, a mutual attraction occurred between the flux of the bar magnet and the circular flux of

the conductor. This resulted in the movement of the movable conductor in a direction that, provided the current is strong enough, will tend to place it at right angles to the axis of the magnet.

By means of these and other experiments, Ampère proved that parallel electric currents attract each other when they flow in the same direction, and repel each other when they flow in opposite directions.

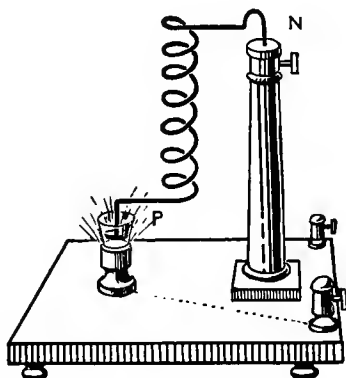


FIG. 33.—ROGET'S OSCILLATING SPIRAL

Since a conductor wound in the form of a hollow spiral will have the current in its neighbouring parallel spirals flowing in the same direction, and since parallel currents attract each other, if the spiral is suspended from the top of a vertical stand as shown in Fig. 33, so that its lower end dips in the mercury in the cup P, then, when a powerful current is passed through the circuit, the attraction between the neighbouring coils of the spiral lifts the spiral out of the cup and thus breaks or opens the circuit. The

attraction no longer existing, the spiral lengthens by its weight, and the lower end, again dipping in the mercury in the cup, again closes the circuit, when the spiral is again drawn out of the cup, breaking the circuit. These successive breakings and makings of the circuit result in rapid to-and-fro motions of the spiral, and, since at each break a bright electric spark is produced, the result is quite brilliant.

The apparatus above described was devised by Roget, an English physicist, Professor of Physiology in the Royal Institution of London, and is called Roget's oscillating spiral. It was one time employed as an automatic make-and-break for rapidly opening and closing the circuit of a piece of apparatus, known as the Ruhmkorff induction coil, that will be described in "The Wonder Book of Electricity."

But by far the most important result of Oersted's great discovery was that it showed how a variety of magnets called electro-magnets can be made. This will be discussed in a subsequent chapter.

CHAPTER XII

ATTEMPTS TO EXPLAIN THE CAUSE OF MAGNETISM

MANY attempts have been made to account for the phenomena of magnetism. While it is not my intention to discuss these attempts fully here, since I do not think such a discussion would pay, yet I will briefly tell you some of the remarkable ideas the ancients had.

Both Thales and Anaxagoras believed that a magnet possessed a kind of soul, intelligence, or immaterial spirit; that the movements of the magnet either towards the north or south poles of the earth, or towards or from the poles of other magnets, were due to the action of this soul or intelligence.

Epicurus, the famous Grecian philosopher, who taught that the supreme good of life consists in enjoying one's self, by eating good things and in doing things that cause bodily pleasure, gravely asserted that the ability of pieces of soft iron or steel to hold on to the poles of magnets was due to the fact that they were provided with hooks. Another man, a follower of Epicurus, declared that iron was the natural food of the magnet; that the peculiar motions of iron, when drawn towards a magnet, occurred while the iron was being eaten or devoured. I am not quite sure just what this man meant, but I suppose he intended to say that these movements were merely the squirmings or death agonies of the iron.

If a magnet possessed but one pole only, it would, per-

haps, have been easier to account for magnetic phenomena, but since it possesses two poles, and these poles have opposite properties, it is more difficult to explain the cause of magnetism. One of the early explanations was that magnetism is due to the presence in the magnet of two different kinds of fluids. In this, as in all explanations, in order to satisfactorily account for magnetism, an endeavour was made to explain what happened to a bar of steel that possessed no magnetic properties whatever until it was brought under the influence of a magnetising force, as for example when touched by the pole of a magnet. The double-fluid theory of magnetism claimed that there existed in all magnetisable substances two fluids, a north or boreal fluid, and a south or austral fluid; that when a body was magnetised, these fluids, which were ordinarily combined and, therefore, neutralised or masked each other's presence, were separated and driven to the opposite ends of the bar, thus producing a north pole at one end, and a south pole at the opposite end, with no magnetism whatever between them or at the magnetic equator. I may say that this explanation of magnetism was generally accepted until the experiment was made of cutting a bar magnet in two at its equator. If the double-fluid theory was true, it should be possible to obtain a magnet that possesses north polarity or south polarity only. But when, as already explained, this was found to be impossible, the double-fluid theory of magnetism was necessarily abandoned.

It was not long after the great discovery by Oersted, referred to in the preceding chapter, that a series of investigations were begun (September, 1820) by the French physicist, Ampère. Starting from the principle that an

active circuit possesses all the properties of a magnet, Ampère set about trying to discover how it would be possible to account for magnets on the assumption that they were caused by electric currents.

At that time it was generally believed that the very small particles of magnets naturally possess magnetic properties. Ampère, therefore, attempted in different ways to account for the cause of magnetism by assuming that the very small particles of matter known as molecules were naturally magnetic, and that the cause of their magnetisation was the presence of minute electric currents flowing through them. At last he succeeded in framing a hypothesis that seemed to meet in a remarkable manner the requirements of the case.

During these investigations, as soon as Ampère thought of a possible explanation to account for magnetism, he tried to construct apparatus to test its probability, and when the apparatus failed to work, as it often did, he threw it away. In this manner he was obliged to throw aside as useless many pieces of apparatus. You see, therefore, he thought of explanations one day, only, after actual trial, to throw them aside the next day. At last, however, he thought out an explanation which, in a modified form, is to-day generally accepted as the cause of magnetism. Let us, therefore, examine Ampère's explanation of the cause of magnetism.

Ampère asserted that the molecules of a magnet are naturally magnetic because they have currents of electricity flowing through them in what are known as closed circuits; that is, where the electric current, after starting from some point in each molecule, flows through or around

the molecule until it again comes to that point, when it again goes on flowing and continues this practically forever.

As soon as Ampère had framed this theory, seeing that the magnetised molecules could easily be represented by short conducting wires bent on themselves in the shape of circles, he began trying to devise some plan by which copper

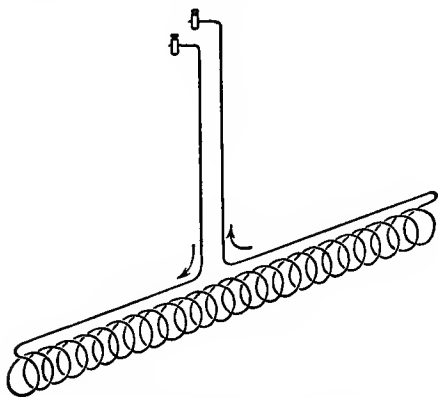


FIG. 34.—AMPERE'S SOLENOID

or other electrical conducting wires might be so bent as actually to form a number of closed circuits.

In Fig. 34 a conducting copper wire has been wound around the surface of a cylinder in equi-distant coils, and its ends, led back along the length of the coil, have afterwards been bent so that the coil can be suspended in mercury cups. When a current of electricity flows through such a suspended system, previously placed in an east and west direction, it will, as soon as the current begins to flow, tend to point, approximately, towards the north of the earth. In other words, the coiled wire acquires all the

properties of a magnet, and, like a magnet, tends to place itself approximately due north and south.

Ampère called this coil a helix or electric solenoid. This was, indeed, a beautiful experiment. Whether the theory was true or not, it showed how a series of parallel circuits through which a current of electricity was flowing

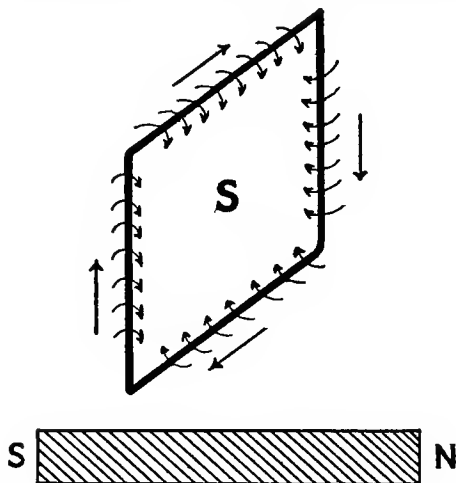


FIG. 35.—DIRECTION OF CIRCULAR FLUX IN RECTANGULAR CIRCUIT

could be made to acquire all the properties of a bar magnet.

You may possibly think that Ampère's electric solenoid did not consist of a number of parallel active circuits only, since, besides such circuits, it had a straight wire passing in the general direction of the length of the solenoid, and, moreover, it contained a number of short pieces of wire connecting the contiguous circular coils. I acknowledge this is true. If you were older, I could make you under-

stand that these two extra conductors completely neutralise each other, since their currents are flowing in opposite directions, so that the solenoid does consist practically of the separate parallel circuits that Ampère declared existed in all magnets.

Now, as Oersted's discovery has shown that a conductor through which an electric current is flowing has

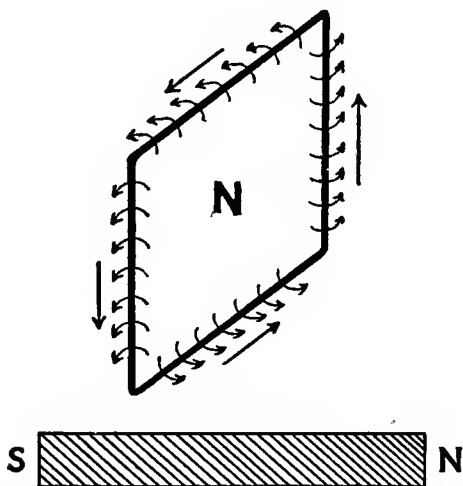


FIG. 36.—DIRECTION OF CIRCULAR FLUX IN RECTANGULAR CIRCUIT

flux produced that flows around it in concentric circles in planes at right angles to its axis, it follows that, in Ampère's electric solenoid, there would be produced circular magnetic flux around the conducting wires of each of the separate circles. There would, therefore, be produced in the solenoid flux that passes or threads through its coils at one end, and emerges or passes out at the other end. Now the end of a solenoid at which flux enters acquires a

south magnetic polarity, and the end at which it passes out, a north magnetic polarity. Consequently, such a solenoid must possess all the properties of a bar magnet whose poles are situated at the end of its axis.

If, therefore, a bar magnet has one of its poles brought near to the end of a solenoid, it will attract or repel the solenoid according to whether its pole is of the same or opposite polarity to that of the solenoid.

Again examining Fig. 32 (see page 121), where a small rectangular circuit is conveying an electric current, there will be no difficulty in understanding why such circuit tends to place itself at right angles to the straight bar magnet placed below. Suppose, as represented in Fig. 35, this rectangle has an electric current flowing through it in the direction represented by the straight arrows, then there will be produced magnetic flux that, as represented by the small arrows, enters this face of the rectangle, and thus produces a south magnetic pole. But if, as in Fig. 36, the direction of the current through the rectangle be changed, so that the circular flux paths will take the direction shown, the flux will appear to pass out of this face of the rectangle, thereby producing a north pole.

Now, if the rectangle is readily movable, it will be moved by the mutual action of its flux and the flux of the bar magnet until the flux from the magnet passes through its south face or end; and to do this the rectangle must place itself at right angles to the length of the bar magnet.

You will naturally ask what produces the currents of electricity that Ampère assumed are constantly flowing through the molecules of either magnetised or unmagnetised iron or steel, so as to endow them naturally with mag-

netic properties. It is well known that all circuits with which we are acquainted possess a resistance that opposes the passage of the electric current, and that, in order to cause an electric current to flow through any circuit, energy must be expended. It would, therefore, seem impossible for electric currents to flow continually day after day, year after year, through the molecules of substances capable of being magnetised, unless there was some source of energy to keep them flowing. This difficulty has caused Ampère's theory of magnetism to be generally rejected by scientific men, although it must be confessed, now we have learned more about the properties of atoms and molecules, that it does not seem so improbable. Indeed, Sir Oliver Lodge, one of the foremost of living English electricians, says concerning this matter:

“To all intents and purposes, certainly atoms are infinitely elastic, and why should they not also be infinitely conducting? Why should the dissipation of energy occur in respect to an electric current circulating wholly inside an atom? There is no reason why it should.”

In accordance with Ampère's explanation as to the cause of magnetism, it is assumed that the molecules are naturally magnetised by the constant passage of an electric current through them in a closed circuit. You may, therefore, ask why there should be any necessity for magnetising them if they are already magnetised. The answer is simple. They must be subjected to some process of magnetisation in order to insure that all their many poles are turned in the same direction. When unmagnetised, the molecules and, consequently, their poles point in different directions, so that the opposite poles neutralise each other, just as they

did in the tube filled with iron filings by De Haldat that lost all its magnetism when shaken so as to prevent their like poles from all pointing one way.

The theory of magnetism that is most generally accepted to-day may be regarded as a modification of Ampère's theory. A magnet is supposed to have its ultimate particles of matter, possibly its molecules, inherently or naturally magnetised; each molecule possesses north and south polarity, and this without attempting to explain how this polarity has been caused. This polarity may be caused by the presence of closed electric circuits or it may be caused in some other way. It is simply assumed that the ultimate particles are naturally magnetic. Now, this being the case, the act of magnetisation consists in simply so turning these particles that their like poles shall all face in the same direction. As soon as this has been done, the substance will be magnetised as powerfully as it possibly can be; or, in other words, the magnet is saturated with magnetism.

If this theory be accepted as true, one can easily see why it is much more difficult to magnetise a bar of hard steel than a bar of soft iron or soft steel, since the particles of hardened steel are more difficult to turn round than are those of soft iron. Then, too, a bar of hard steel having once been magnetised, tends to retain its magnetism, after the removal of the magnetising force, by reason of the very fact that it is so hard to turn these molecules.

The theory of magnetism that is most generally adopted to-day assumes, in order to account for the flux produced by every magnet, that its separate molecular magnets possess the power of producing either whirlings in the sur-

rounding ether, or an actual forward motion of the ether whereby it is expelled or blown out of their north poles. I have purposely assumed the forward or blowing motion of the ether in preference to the vortical or whirling motion, not only because the blowing motion is easier for you to understand, but especially because, in a certain sense, so far as the effects they produce, the two motions are practically the same.

It will be noticed in the above that I have referred to the ether as constituting the imponderable substance that is blown out at the north pole of the magnet and sucked in at its south pole. Without going into an explanation here I will say that the universal ether is an imponderable and extremely tenuous form of matter that fills, not only the spaces between the atoms and molecules, but also the greater spaces between the stars and other heavenly bodies. It is through the universal ether that the light and heat of the sun are propagated by means of waves.

CHAPTER XIII

MAGNETS THAT CAN READILY FORGET THEY HAVE BEEN MAGNETISED

I REMEMBER, when I was a boy, that every now and then the volunteer fire companies of the city of Philadelphia had good-natured competitions in order to see which of their engines could throw the best stream of water. The question was not only how far these streams could be thrown, but also how much water they contained. In a similar manner, it was only during last year that the Paid Fire Department in Philadelphia had trials in order to find the height streams of water could be thrown from the high-pressure mains that have recently been located in the central portions of the city, in order the better to protect the sixteen, eighteen and twenty-story skyscrapers that have been erected.

If a somewhat similar trial were made between permanent and electro-magnets I would back the electro-magnets to win every time, both as regards the quantity of magnetic flux they can produce, as well as the distance to which they are able to blow it. Let us, therefore, try to understand the peculiarities of electro-magnets; for, on account of their great importance, I especially wish you to learn their construction and operation.

In the first place as to how electro-magnets are made: I have already explained how the turns of conducting wire of an electric solenoid through which an electric current is

passing have circular magnetic flux produced around them, and how this flux is able to set up strong north and south poles as it is blown out of the coils at one end and sucked in again at the opposite end. You can, therefore, understand why it was, when Arago, a French physicist, held a small length of copper wire, through which a powerful electric current was passing, in a mass of iron filings, that the filings clung to it in parallel circles corresponding to the circular lines of magnetic flux that are always set up around an active conductor.

You probably know that electrified bodies draw or attract towards them small particles of dust or other light bodies in their neighbourhood. If a glass rod or a hard copper comb is electrified by rubbing it briskly against the coat, it will attract light bodies such as feathers, powdered charcoal, dust, etc. Arago, of course, knew this and thought that, perhaps, the iron filings had been caused to cling to the copper wire by means of electric attraction. To test this he plunged the copper wire in powdered glass, and also in finely divided copper dust. There was no attraction, so he came to the conclusion that the iron filings clung to the copper wire, through which an electric current was passing, simply by reason of the attraction of its magnetic poles.

But it was not only Arago and Ampère who were thus experimenting in the direction in which Oersted had pointed out. Sir Humphrey Davy, in England, also began trying to find out how steel could best be magnetised when brought in different ways near an active conductor. In this way he soon discovered that an active conductor could produce the best results, in magnetising straight bars of

hardened steel, when the bars were placed inside a hollow coil through which the current flows.

Since the magnetic polarity produced by an electric current depends on the direction in which the current is flowing, it is easy to change the position of the poles produced when a bar of steel is placed inside a hollow coil by changing the direction in which the current flows through the coil. If, for example, the current has been flowing into the end of the wire from the top to the bottom of a coil or solenoid, or from its right-hand side to the left-hand side, then the polarity will be changed by



FIG. 37.—RIGHT-HANDED HELIX

causing the current to flow in from the bottom to the top, or from the left-hand to the right-hand side.

But there is another way in which the polarity of a coil or solenoid can be changed, and this is by changing the direction in which its wire is wound or coiled. There are only two ways in which wire can be coiled on a solenoid; namely, as a right-handed solenoid or helix, or as a left-handed solenoid or helix. In a right-handed solenoid or helix the winding is clockwise; that is, the wire is wound in the direction in which the hands of a watch or clock move over its dial face. Now this is by no means an idea that is easy to grasp, and yet you must grasp it if you would understand what I am about to tell you.

Hold a lead pencil in a horizontal position so that its blunt end points directly towards you. Now take a piece of wire and begin winding it on the end nearest you in the



LIFTING PIG IRON WITH AN ELECTRO-MAGNET

The magnetism is instantly produced on the closing of the circuit and lost on its opening.

By courtesy of P. F. Collier & Son

same direction as that in which the hands of a watch move. Such a spiral would be wound clockwise, or would be a right-handed helix. If the winding is in the opposite direction, it will be a left-handed winding, or counter-clockwise. A right-handed helix is represented in Fig. 37, where, as you can see, the windings are clockwise, and a left-handed helix is represented in Fig. 38, where the windings are counter-clockwise, provided in both of these cases you are looking at the helix when its left-hand end is turned towards you.

If you examine the above drawings carefully you will see that the direction in which the magnetic flux encircles the wire of the helix varies with the direction in which the



FIG. 38.—LEFT-HANDED HELIX

current is flowing through it, and that, moreover, the direction in which the magnetic flux will thread through the helix from one end to the other will depend not only on the end of the helix at which the current begins to flow, but also on the direction of its winding.

You can easily convince yourself of this fact. Take, for example, the right-handed winding shown in Fig. 37, when looked at from its left-hand end. Holding this next to you, it is clear that the coil is wound in the same direction as that in which hands of a watch move over its dial. If, however, you hold the right-hand end next to you, and note the direction in which the wire winds around the helix to the other end, you will see that it is left-handed, or winds in the opposite direction to that of the hands of a

watch. In other words, a winding that is right-handed when regarded from one end of a helix is left-handed when regarded from its other end. This is the reason the polarity of the helix is reversed by causing the current to enter at its opposite end.

It is easy to produce consequent poles; *i. e.*, two free poles of the same name at any point intermediate between the ends of a helix. To produce such poles it is only necessary to change the direction of the winding.

Again examining the figures that represent the direction in which the flux passes through the conducting loop, it

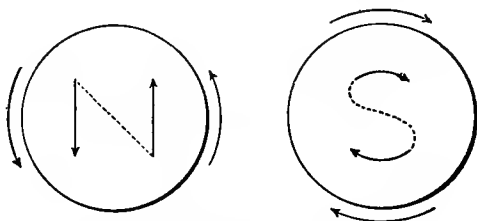


FIG. 39.—POLARITIES OF SOLENOIDS

will be seen that in order to produce a north pole at one end of the solenoid, it is necessary to cause the magnetic flux to come out of the solenoid at that end; and, similarly, to produce a south pole, it is necessary to cause the flux to pass into it at that end. If, then, you remember the direction assumed by the circular flux that is produced by an electric current passing vertically through the card already shown in Fig. 26, you may be able to reason out for yourself the direction in which the current must flow through the circuit in order to cause the flux to pass in the required direction through the solenoid.

As the prediction of the polarity of a solenoid requires considerable thought, endeavours have been made to simplify the matter. For example, it has been suggested that if, as shown in Fig. 39, N and S represent the ends of a bar of soft iron around which coils have been wrapped, and the current flows through the coils in the directions indicated by the arrows on the outside, the polarities produced will be north and south respectively.

For example, in the left-hand figure, if the current, as indicated by the curved arrows, flows in a counter-clockwise direction, a north pole, N, will be produced at the end facing the observer. Or, printing the letter N in the manner shown, with its two vertical lines consisting of arrows pointing in the directions indicated, these directions will show how the current must flow through the wire in order to produce a north pole at this end.

In the same way, at the right figure, in order to produce a south pole on the end of the bar facing the observer, the direction of the current through the coils must be clockwise, or the same as the curved arrows forming the top and bottom of the letter S.

The different kinds of windings that are capable of producing north and south poles, and the directions the currents through these windings are required to have to produce the polarities marked at the ends of the soft iron bars, are shown in Fig. 40.

We are now ready to examine the construction of an electro-magnet. Strictly speaking, an electro-magnet differs from an active coil or helix only in that, in an electro-magnet, the coil or helix has been provided with a soft iron core. A coreless helix or solenoid cannot prop-

erly be called an electro-magnet. It is simply a magnetic solenoid or helix. I especially wish you to remember this since, otherwise, we should properly regard Ampère as the inventor of the electro-magnet; for he was the first who showed that a rectangular circuit, consisting of a single wire, acquires all the properties of a magnet both as regards its powers of attraction and repulsion, as well as its power of pointing, approximately, to the north of the earth. And even if it be urged that a single coil of this character should not be regarded as a magnet, then we might still point to Ampère's solenoid and call it a magnet, or we

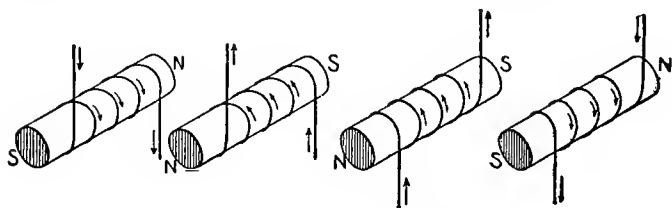


FIG. 40.—WINDINGS OF SOLENOIDS

might point to Schweigger's multiplier with its closely wound coils and call that a magnet. But if we limit the term electro-magnet to a helix or solenoid provided with a soft iron core, then we must give the credit for this great invention to William Sturgeon, who was the first to introduce the core of soft iron.

I acknowledge that this use of a soft iron core does not at first sight seem to be a great invention. The solenoid had been produced before Sturgeon's time. It was known that a bar of steel introduced into a solenoid becomes strongly magnetised, and I think it more than probable that straight soft iron cores had also been introduced into solenoids before Sturgeon's time. Nevertheless, it seems

that Sturgeon was the first purposely to bring these two things together; *i. e.*, the coil and the soft iron core, to form a fixed piece of apparatus, the core of which was not afterwards intended to be withdrawn.

You have probably often regretted that your memory is not more reliable, and have pictured to yourself how great an advantage you would possess if you could calmly store away facts in your memory with the absolute certainty that you could promptly recall them whenever needed. You may be certain that you have facts stored away somewhere in your brain. You are sure they are there. Indeed, you prove this by afterwards remembering them; but, try as hard as you may, there are times when you find it impossible to recall these facts.

Now I do not doubt that you will be surprised when I tell you that one of the great advantages possessed by electro-magnets over permanent magnets is that they are able almost instantly to forget they ever were magnetised.

An electro-magnet differs greatly in this respect from a permanent magnet. A bar of hardened steel, when properly magnetised, appears practically never to forget that it has been magnetised. Its magnetic retentivity, or, as it is also called, its magnetic memory, is exceedingly tenacious. It can remember for years that it has been magnetised.

Now do not understand me to say that a good magnetic memory is to be despised. On the contrary, it is an excellent thing in such a device as a compass needle, since, as you can see, it would be very awkward if a navigator, going some day to examine his compass needle, should find it had forgotten it had been magnetised, and had, therefore, ceased to point, approximately, to the north.

Suppose, however, you wish to use a magnet for the purpose of ringing a bell, or for sounding an alarm, where it is desired that the bell shall receive a number of strokes rapidly following one another. For such purposes a permanent magnet would be useless, since if the magnet was very strong and the steel very hard, a considerable time would be required both before it became a magnet or before it lost its magnetism.

There are **two** reasons why electro-magnets are so valuable:

1. Because they possess the property of both instantly acquiring their magnetism on the closing of an electric circuit through the magnetising coils, and of instantly losing their magnetism on the opening of such circuit.

2. Because they possess enormously greater strength; that is, are capable of producing a much greater quantity of magnetic flux than any other form of magnet.

To give you some idea how rapidly a well made electro-magnet with a core of soft iron is able to acquire and lose its magnetism, I will say that in a form of small electro-magnetic engine invented by Page, its magnetism can be made, lost and reversed 4000 times a minute, and in other pieces of apparatus even this great speed is increased.

You will be interested in examining the form of electro-magnet first constructed by Sturgeon. As shown in Fig. 41, it was of the simple horseshoe type, the soft iron core of which was wrapped with insulated wire. When the electric current flows through the coil by inserting the terminals of an electric source in mercury cups, north and south poles are instantly produced at the extremities of the soft iron core.

I think an electro-magnet is, beyond doubt, one of the most important if, indeed, not *the* most important electric and magnetic device ever produced. I am sure all of you who have read about the wonderful things in both electricity and magnetism that electro-magnets are capable of accomplishing will understand that this means very much. The great value of the electro-magnet consists in the wonderful rapidity with which it can be magnetised and can

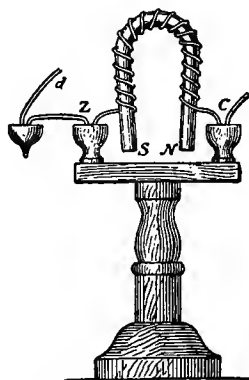


FIG. 41.— STURGEON'S ELECTRO-MAGNET

afterwards lose its magnetism; for, instantly when the current flows through its coils it becomes a magnet, and instantly when the current ceases to flow, by opening the circuit, it loses its magnetism. Moreover, the places or points where the electric circuit can be made or broken may be situated thousands of miles from the electro-magnet. Without electro-magnets it would be impossible to have the electro-magnetic telegraph, the telephone, burglar alarms, or annunciator calls.

But this is not all. The enormous increase in the strength of electro-magnets, due to the introduction of a soft iron core, renders it possible to use electro-magnets for such apparatus as dynamo-electric machines and electric motors. Without electro-magnets, therefore, arc and incandescent electric lighting would be impossible; the driving of mills and machinery or trolley cars by electric motors would be impossible, as would also be the very important principle of the transmission of power by means of electric energy. Indeed, I think you would find it difficult to conceive how a greater calamity could be brought on the world than would befall it were it deprived of all its electro-magnets.

Before closing this brief chapter on the general construction and operation of electro-magnets, I wish to tell you what Professor Henry of Princeton University did for the electro-magnet.

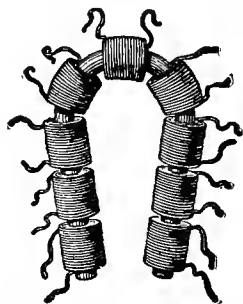


FIG. 42.—HENRY'S
ELECTRO-MAGNET

Henry devised a form of instrument called a high-resistance electro-magnet, the construction of which is shown in Fig. 42. Here a number of separate coils are placed, as shown, over the surface of a horseshoe-shaped core of soft iron. The advantage was

thus obtained of being able to connect the separate circuits in different ways so as to vary the strength of the magnet, as well as to make it suitable for use with different electric sources.

CHAPTER XIV

DIFFERENT KINDS OF ELECTRO-MAGNETS

THE electro-magnet, with its soft iron cores wrapped with coils of insulated wire, is of such simple construction that it can readily be made in a number of different forms or shapes. We will describe a few of these.

The simplest form of an electro-magnet consists of a straight cylindrical bar of soft iron covered with coils of insulated wire. These coils must necessarily be insulated since it is necessary that the electric current shall pass in

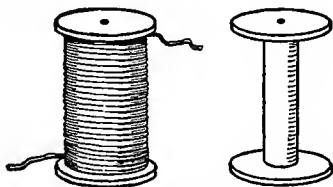


FIG. 43.—CORE AND BOBBIN OF ELECTRO-MAGNET

at one end of the wire and come out at the other end without taking any short cuts, as it would if the coils of wire touched one another at any point. In this, as in almost all forms of electro-magnets, the coils of wire, instead of being wrapped directly on the surface of the soft iron cores, are generally wound on a bobbin, or spool, consisting of some form of insulating material such as wood, hard rubber or pasteboard soaked in shellac varnish. The spool is provided with ends that project beyond the top layer of

wire. This is necessary, since, unless the ends of the core are provided with some such device, the coils are apt to slip off. Such a core and bobbin are represented in Fig. 43.

In practically all electro-magnets, the core is covered with more than a single layer of wire. In such cases the wire is wound in turns, placed close together, from one end of the core to the opposite end, say from the top to the bottom. It is necessary that the direction of the winding be maintained throughout; that is, it must all be either right-handed or left-handed. The second layer is wound over



FIG. 44.—HORSESHOE ELECTRO-MAGNET

the first, returning in the opposite direction; *i. e.*, from the bottom to the top, and in this way the coils of wire are placed, layer after layer, on top of one another, the same direction of winding being maintained throughout.

It makes no difference in the polarity because the current flows through the separate layers in opposite directions when they are wound in this manner; provided the same right-handed or left-handed method of winding is preserved in all the layers, each separate layer will tend to produce north polarity at one end and south polarity at the

opposite end; for, as we have seen, a coil whose winding is right-handed when observed from one end, is left-handed when observed from the opposite end.

The commonest form given to the electro-magnet is that of a horseshoe. The wire may be wound directly on the core, beginning at one end and continuing to the other end, keeping the same direction of winding on each of the legs throughout; that is, seeing that the winding shall be either clockwise or counter-clockwise. If, as is usually the case, more than a single layer is wound on the core, the separate layers are placed on one another, as has been described in the case of the straight bar electro-magnet.

A horseshoe electro-magnet so wound is represented in Fig. 44. Here the direction of winding has been maintained throughout just as if the core or bar had been straight when wound, and had afterwards been bent in the form of a horseshoe.

For small electro-magnets, it is generally more convenient to wind two separate coils on bobbins or spools and then slip them on two separate cores, one set of the ends of which, as shown in the above figure, the lower set, are firmly connected together by a soft iron yoke. The ends of the coils are then so connected as to preserve the same direction of winding on each core. This leaves the two free poles. It is customary in all electro-magnets to leave the poles projecting a short distance beyond the ends of the spools, in order to ensure a freer play to the armature as it moves to-and-fro.

Fig. 45 shows the form of electro-magnet that consists of a bar of soft iron on the two legs or poles of which two spools of insulated wire have been placed. In this form,

the soft iron core, instead of consisting of two separate straight iron bars and a yoke, is formed of a single bar bent into the horseshoe form. The magnet, suspended as shown from the top of a frame, is provided with a suspension plate for the reception of weights.

A cylindrical form of electro-magnet devised by Joule, an English physicist, represented in Fig. 46, is of the

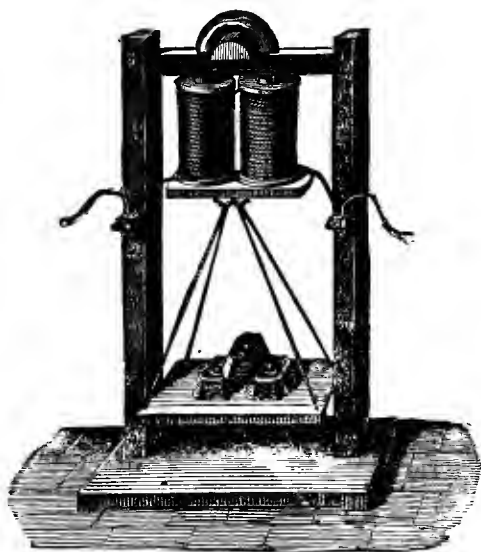


FIG. 45.—A FORM OF ELECTRO-MAGNET.

horseshoe type. When its armature is in place against the poles this magnet has the form of a cylinder. The core consists of a hollow cylinder of wrought iron, planed off on one side so as to make a gap or opening of about a third of an inch wide between the two sides. The armature con-

sists of a piece of soft iron shaped so as both to fit in close contact with these poles, as shown, and to complete the cylindrical outline. The larger piece of the cylinder is covered with insulated copper wire. When an electric current is sent through the coils, opposite poles are produced at the openings that attract the armature with considerable force. In the cylindrical horseshoe magnet there is such an extent of polar surfaces that the armature is held to the magnet poles with considerable force.

Another curious form of electro-magnet is known as an iron-clad electro-magnet. This magnet, as represented in

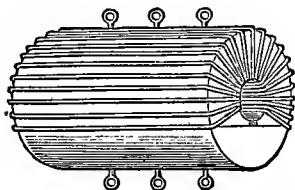


FIG. 46.—JOULE'S CYLINDRICAL ELECTRO-MAGNET

Fig. 47, takes its name iron-clad from the fact that its magnetising coils are completely surrounded by iron. A soft iron cylinder, that has been brought into firm contact with the lower pole, surrounds the magnetising coil and reaches up to the level of the upper pole. In this manner two concentric poles are produced that are capable of exerting a considerable attraction on a suitably shaped soft iron armature brought near them.

A still more curious form of electro-magnet consists of what is known as the zigzag-magnet, also devised by Joule. This magnet, as represented in Fig. 48, is wound as shown

so as to produce a number of alternate north and south poles, and is employed in some forms of alternating-current dynamo-electric machines.

The powerful electric currents that are now produced in nearly all the large cities of the world, either for the supply of systems of arc and incandescent electric lighting, or for the driving of electric motors or trolley cars, make it easy to produce electro-magnets enormously stronger than the great magnetic battery produced by Knight that was

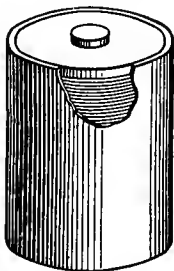


FIG. 47.—IRONCLAD ELECTRO-MAGNET

justly regarded in its time as one of the world's great magnetic wonders.

A brief description of a large electro-magnet that was made at the United States torpedo station at Willet's Point on Long Island Sound will interest you. Here a huge steel cannon, some sixteen feet in length, weighing 50,000 pounds, was wrapped with 5250 turns of insulated wire. When a powerful electric current was sent through the coils, the quantity of magnetic flux that was blown out from its north pole and sucked in again at its south pole made this huge electro-magnet one of the greatest magnetic blowers and suckers the world had ever seen.

Let me tell you some of the many wonderful things this magnet was capable of doing.

It could support five cannon balls hanging one under another, something like the needles or pins you may have seen suspended from the poles of a small bar magnet. How great, however, the difference in weight! Each of these

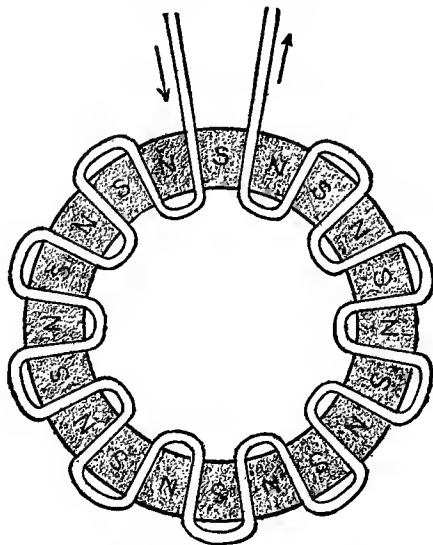


FIG. 48.—ZIGZAG MAGNET

balls weighed 250 pounds, so that a total weight of 1250 pounds was suspended by only the small contact existing between the spherical surface of the ball and the magnet pole. Had a flat armature been placed on such pole a much heavier weight might have been supported. Indeed, when an armature was so placed against the plate it required the united strength of sixteen able-bodied men,

tugging at a rope and tackle, to pull it from the magnet. Contrast this with the 100 pounds that was sufficient to separate a bar of soft iron from the poles of Knight's great magnetic battery.

This was truly a wonderful cannon and many interesting things were done with it. A soldier stood with his back towards the north pole of the huge magnet; the flux blown out from this pole passed almost as freely through his body as if it were not there, and its presence was shown by the clinging of heavy iron spikes to his forehead and chest. The flux passing through the man produced powerful south poles where it entered his body and powerful north poles where it passed out. It is these north poles that caused the iron spikes to hang on to him.

You may inquire whether the soldier experienced any inconvenience from this passage of the magnetic flux through his body. I will discuss this matter in another chapter, but so as to remove any doubts you may have, I will say that no injurious effects could be detected.

There is another form of electro-magnet that differs from any already described, in that the soft iron core is movable instead of being fixed. This magnet is known as a sucking magnet. It consists of a hollow coil containing many layers of insulated wire and a core of soft iron, so much smaller in diameter than the opening of the coil that it can move through it without touching at any place. As soon as an electric current is sent through the coil, the movable core, if brought near it, is sucked or drawn into the coil, in which it remains suspended, as it were, in mid-air.

There is a tradition that in the Mohammedan mosque

where the body of Mahomet the Prophet is buried, the iron coffin containing his body is sustained in mid-air between the roof and the floor of the mosque by some invisible force. I do not know whether this is true or not, but I think it very improbable, although the soft iron core of the sucking magnet described in the preceding paragraph could and did remain suspended in mid-air when a sufficiently powerful magnetising current passed through its coils. Provided cost were a matter of indifference, such a phenomenon might easily have been actually produced, but the amount of electric current that would be required to operate a sucking magnet coil, hid in the walls of the mosque, would be so great that a very large and conspicuous electric plant would have to be established somewhere in the neighbourhood.

If, as I have read in other accounts of Mahomet's coffin, the coffin was merely suspended at a point in the ceiling of the mosque without any other attachment, the wonder would cease; for if the coffin and its contents only weighed a few hundred pounds, the suspension of such a weight even from practically a single point would be but a trifle when compared with the 1250 pounds of iron cannon balls suspended from a single point on the pole of the huge electro-magnetic gun magnet already referred to.

It is in the construction of the dynamo-electric machines employed for producing the electricity required for the lighting of large cities and for driving machinery and motor cars that electro-magnets are especially useful. It may interest you, therefore, to hear a few of the things pointed out by Sylvanus Thompson in his "Dynamo-Electric-Machinery" that must be carefully borne in

mind in producing electro-magnets for this purpose. Briefly, these are as follows:

To produce powerful electro-magnets, plenty of iron should be provided for their cores. When the cores are cylindrical in shape, the strength of the magnetism increases as the square of the diameter of the core; or, other things being equal, a magnet that is twice as thick as another (that is, whose diameter is twice as great) will be four times as strong.

The iron should be as soft as possible, not so much because soft iron is readily magnetised and de-magnetised, but because soft iron is not so quickly saturated as hard iron.

It is especially important, wherever there are joints in the iron of electro-magnets, as, for example, in the pole pieces or yokes, that these joints be as close fitting as possible and, therefore, free from air-gaps, so as to make the magnetic resistance or reluctance of the circuit as small as possible.

CHAPTER XV

THE MAGIC WAND AND PURSE OF FORTUNATUS

HAVE you ever thought what a wonderful thing a fairy's wand is? The fairy has only to touch a thing with it to bring about a great change. Sometimes the wand changes a man or a woman into a wild beast. Sometimes it leaves them alone and only changes their clothes; sometimes it changes neither the appearance nor the clothes but only endows them with new qualities or powers. How nice it would be to have a fairy's wand, so that we could go about touching people or things so as to change them. I suppose this is the idea of the wand employed by the modern magician when he does his tricks of legerdemain, pretending that it is the magic powers of the wand that enable him to perform them.

I imagine that some of you, remembering how I have employed fairy stories to impress certain facts on your mind, are saying to yourselves: Now I wonder what Dr. Houston can possibly find in magnetism, or in a magnet, that in any way resembles a fairy's wand?

If you will wait a few moments, I am sure I will be able to prove that it is indeed possible to find such a wand in a magnet.

Probably all of you have heard the fairy story of Fortunatus; how a fairy whose good feeling he had won made him the present of a famous purse, or—more correctly—brought about a change in his own purse that greatly sur-

prised him. Disguised as an old woman clothed in rags, the fairy appeared to Fortunatus and asked for help. Now I am sorry to say that Fortunatus had been "burning his money up," or in other words squandering it, so that there were only ten pieces of gold left in his purse. He was a generous fellow, however, and when the old woman, who seemed to know everything, asked Fortunatus to give her ten pieces of gold to save herself and her large family from starving, he answered:

"I have but ten pieces of gold left in my purse, but take them, my good woman. I'll manage somehow or other."

No sooner had the old woman taken the ten pieces of gold Fortunatus offered her than she turned into a beautiful fairy. Smiling at the surprise that was seen in the face of Fortunatus, she said:

"Fortunatus, you will never regret the kind deed you have just done in giving me all you had left in your purse. Let me see that purse again"; and when Fortunatus held it towards her she touched it with her wand and said:

"Never while the purse remains in your possession shall you fail to find in it ten pieces of gold. No matter how often you may take the ten pieces of gold from that purse, you shall find ten pieces still remaining in it."

Fortunatus thanked the fairy for the manner in which by a single touch of her wand she had given him such wonderful resources. He found that, as the fairy had promised, he could never empty his purse, although he tried his best to do so. Of course with so great a fortune at his command, he travelled over different parts of the world and had great times.

Now here are two wonderful things. A magic wand and an inexhaustible or, perhaps, as you might call it, an un-emptiable purse. With the first, one can instantly change any object the wand touches. With the other, one can keep on drawing something out of a receptacle in which it has been kept, without decreasing the quantity that remains. You might say that you would willingly take a long walk to be able to see anything that possessed either of these wonderful properties. Well, you will not have to go far to see such a thing; for, an ordinary magnet, or a little piece of magnetised hardened steel or lodestone, actually possesses both of these properties.

Of course you have a pocketknife or penknife. If so, try to get it magnetised. This is simple, if you can find anyone who has a strong electro-magnet. You need only place the knife across the two poles and let it remain there for a few moments, when it will become thoroughly magnetised.

Now what I am about to tell you of the magic powers of a magnetised knife-blade is true only if the knife has been made of good and properly hardened steel. If it is a cheap knife, the blades of which are of soft steel, it will lose its magnetism almost as soon as it is removed from the magnet poles, and will, therefore, be worthless for what I am about to describe.

If it so happens that you live somewhere at a distance from an electro-magnet, or are unable to get permission to place your knife across its poles when the current is flowing, you can magnetise your knife-blade by placing it against the poles of a permanent magnet, although, generally speaking, an electro-magnet is preferable because, as

we have seen, an electro-magnet is generally more powerful than an ordinary steel magnet.

After you have magnetised your penknife, in order to convince yourself that it possesses magnetic properties, open one of the blades and bring it near a small piece of steel, say a sewing needle that is resting on a table. Instantly the point of the blade will draw or attract the needle towards it, so that if the knife is removed gently from the table it will carry the needle with it, and you can see the very curious sight of the needle swinging to-and-fro and hanging at one end from the sharp point of the knife-blade. You cannot see what holds it, but you know it is the magnetic flux that is either being blown out or sucked in at that end of the penknife blade.

But the magnetised knife-blade can do more than merely pick up the needle. The point of the needle, which has been touched by the knife-blade, has instantly been endowed with a new property. Acting as a magic wand, the knife-blade has given the needle properties it did not before possess; for, if the needle be now floated on the surface of water, it is able to point out or show the way to the north or south pole of the earth. It has been magnetised by the mere touch of your knife-blade and can now act as a small compass needle. In other words, your knife has actually acted as a magic wand.

I wish to say here that in so small a piece of steel as a sewing needle, with so weak a magnet as a penknife blade, the strength of magnetism imparted to the needle is apt to be quite small, so that unless you are skilled in experimenting you may have some trouble in making the floating needle point readily to the north. If you have such trouble,

don't conclude that what I have told you is untrue, but try something larger than a sewing needle. Try the open blade of a penknife that has never as yet been magnetised, and, bringing the blade of your magnetised knife so as to touch or come in contact with the blade of the unmagnetised knife, draw the blade over the other blade, beginning, say, at the thick end where it turns in the knife handle, draw it towards the point, and then, returning the blade through the air, again draw it towards the point, repeating this ten or fifteen times. Now turning the blade over, do the same thing with the other side, and also with the back of the blade. When you have thus completed these motions you will find that the blade of the other knife is now magnetised and will be able to pick up needles and pins nearly as well as your own knife does.

If you dip the blade of your magnetised penknife in a quantity of iron filings, the filings will collect on the ends in the same feathery tufts that you read about being produced when a bar magnet was rolled in iron filings. If you have properly magnetised the other knife-blade it will also be found able to collect iron filings at its point.

But your magnetised penknife blade, which as above described is able like a fairy's wand to endow a thing touched with new properties, is more than a magic wand. It is also like the wonderful purse of Fortunatus. You can take out from it a certain quantity of magnetism, and yet it will have as much magnetism remaining in it as it originally had. Indeed, if you are successful, and go through the strokings carefully as I have explained to you, you can take out from your penknife blade apparently all the magnetism it originally contained; for you can make

the blade of the magnetised knife as strongly magnetic as your own, and yet, when you come to examine your knife-blade, perhaps naturally expecting to find it empty or free from magnetism, you will find it as full of magnetism as before.

Now what makes the matter still stranger is that it makes no difference how many penknives you may magnetise from your knife, if the process has been properly carried on; especially, if you have never tried to magnetise a blade that has been already magnetised, it will make no difference. You will find that the strength of magnetism in your knife is apparently as great as it ever was. Indeed, if the truth were known, it would most probably be stronger than it ever was before. Is it not like the wonderful purse of Fortunatus, in which ten gold pieces taken from the ten in the purse leave ten? One knife-blade full of magnetism, given to an unmagnetised knife-blade, and, therefore, taken from the magnetising knife-blade, leaves one knife-blade full of magnetism in the knife.

Now I shall not be surprised if you should say: "I will not believe any such ridiculous statement no matter who makes it. It is contrary to all common sense, and, moreover, I never have had such an experience."

As regards the matter being contrary to common sense, I hope to be able to prove to you that, so far from this being true, it is exactly what you should expect, if you thoroughly understand what is taking place when your knife-blade is giving magnetism to the other knife-blade. As regards the thing being contrary to your experience all I have to say is, try it for yourself.

But let me see if I can show you that what has hap-

pened to the knife is strictly in accord with common sense. Some people have the idea that in the case of a permanent steel magnet, in order to prevent the magnet from losing its magnetic power, the soft iron armature placed over its poles when removed from them should be taken off gently. Such people say, never remove the armature from a magnet suddenly—if you do you will ruin its magnetism; that is, will cause the magnet to become demagnetised. Now, if this were true, since during the numerous strokings of your knife-blade against the blade of the knife you are magnetising, your knife-blade would be suddenly drawn from the other blade, it would lose its magnetism. But it can be shown, as Professor Sylvanus P. Thompson has done, that, so far from a magnet being weakened by suddenly pulling its armature away from its poles, it is actually strengthened.

But you may say: “How can my knife-blade have as much magnetism left in it as it first had if it is constantly giving magnetism to another penknife?” Now, let us look at this matter and get it clear.

When you stroke the unmagnetised blade of a penknife with the magnetised blade of your knife, the other knife-blade certainly acquires magnetism. It looks as if its magnetism comes from your knife-blade. But it does nothing of the kind. In discussing the theories of magnetism, I told you that, in accordance with modern ideas, it is now generally believed that the very small particles of steel in a magnet, say the molecules, are naturally magnetic; that when such a bar is magnetised, the magnetism is not derived from an external source, the magnetising magnet, but from its own particles, which are naturally magnetic; that

is, which were magnetic before they were brought into the neighbourhood of the magnetising magnet. Before you brought the magnetised knife-blade in contact with the blade that is unmagnetised, the latter was already magnetic, but this magnetism was hidden because the little magnets were arranged in all sorts of positions, with their opposite poles together. Their magnetic flux, therefore, instead of passing outside the magnet, flows in little closed circuits through these tiny magnets. All your knife-blade does, when it is drawn over the surface of the unmagnetised blade, is to catch hold of the little separate magnets and, swinging them around, cause them to point in the same direction. Their flux is thus united so as to flow in a general stream through the bar, coming out at one end, and entering again at the other end. As soon as this is done the bar is magnetised. Your knife-blade has given up none of its magnetism to the other blade, but has simply pulled the molecular magnets around so as to cause them to point in the same direction.

But you may ask what has happened to the little magnets of which your knife-blade consists. Do they all continue pointing in the same direction? I can see no reason why they should not. Indeed, on the contrary, I can see that since, when the other knife-blade has been magnetised, all its little magnets are pointing in the same way, necessarily all the little magnets of the magnetising knife are similarly pointing in the same way; for, otherwise, they could not have been able to turn all the little magnets of the magnetised blade in the same direction.

Before leaving this matter, it may be well to present it to you in a somewhat different light. Not that what I am

about to tell is exactly the same as what I have told you about magnetism. It is simply what may be called an analogous case.

Suppose a baseball player has thoroughly mastered the art of pitching a ball so as to puzzle the batter with his outshoots, inshoots, or drops; or suppose he has learned how to deliver that very perplexing form of ball called a "spit" ball, that so often fools the batter as it comes moving in a straight line directly towards the plate, and just as the batter, sure of its direction, strikes at it, it suddenly drops or rises, thus escaping the bat.

Now, I need hardly tell you, because one has a full knowledge of how to deliver any kind of ball that he will lose this knowledge either because he keeps on practising the delivering of such balls, or because he is willing to impart his knowledge to another pitcher in order to teach him to deliver them. You know, as well as I do, that the more he hands out, as it were, such knowledge, the more he will continue to possess it. It is the same with any kind of knowledge. The fact that you give or impart this knowledge to others only makes it all the more certain that you will keep it yourself.

CHAPTER XVI

DIFFERENT WAYS IN WHICH BODIES MAY BE MAGNETISED

ALTHOUGH there are various ways in which magnetism may be imparted to magnetisable bodies, yet all of them consist in causing magnetic flux to pass through the body, so that it shall enter it at one point and pass out from it at another point.

The simplest method of magnetisation is by touch. The body to be magnetised is simply touched by one of the poles of a strong magnet; or, since this is not apt to pro-

duce a very strong magnetisation, the body is repeatedly touched or stroked by drawing the magnetising pole a number of times over its surface. In all such cases, the body that is magnetised acquires a polarity opposite to that of the pole by which it has been touched or stroked.

It is a matter of considerable importance, in the case of any magnet, that its magnetism be so distributed as to cause the poles to be located at the opposite ends of straight bars or at the free ends of horseshoe or U-shaped magnets. When the bar to be magnetised is a straight bar, and is to be employed as a compass needle, it is especially important

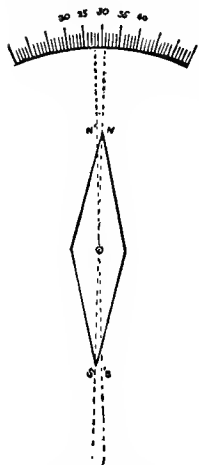


FIG. 49.—ERROR
FROM POSITION OF
POLES

that its opposite poles shall come exactly at the ends or extremities of the needle.

Suppose, for example, it is desired to magnetise the needle NS, Fig. 49, for use either as a compass needle, or as the needle of a galvanometer, so that in either case the exact amount of the deflection of the needle can be readily measured. Now, unless the poles are situated exactly at the extremities N and S, an error will be made in reading the direction in which the needle is apparently pointing. Since it is assumed that the poles of a compass needle actually occupy the positions at its opposite ends, the amount the needle is turned out of its position of rest when under the influence of the magnetism is estimated on this assumption, so that if the poles are located elsewhere an error will result. Suppose, for example, in the needle represented in the preceding figure its N and S magnetic poles, instead of being located at its extremities N and S, are situated at N' and S'. In other words, instead of lying in the direction of the line NS, they lie in the direction of N'S'. Then, while the north pole of the needle is in reality pointing towards 28° on the scale shown in the figure, it appears to be pointing to 31° , thus causing a serious error of 3° .

The magnetisation of a needle obtained by stroking it from end to end with a single magnet pole is known as "magnetisation by single touch." This method is not apt to bring the opposite poles exactly at the extreme ends of the needle. Sometimes, in magnetisation by single touch, the needle is magnetised by rubbing one pole of the magnetising magnet against one end of the needle, and the other pole against its other end. Perhaps, however, the best

method of magnetising by single touch is to place the pole of the magnetising magnet in contact with the needle, drawing it repeatedly along the needle in the same direction. No method of magnetisation by single touch produces very strong magnetisation, and is very apt to produce consequent points.

In what is known as “magnetism by divided touch,” the opposite poles of two separate magnets of exactly equal strength are placed at the middle of the bar to be magnetised, and are then drawn simultaneously in opposite directions towards the ends of the bar. On reaching these

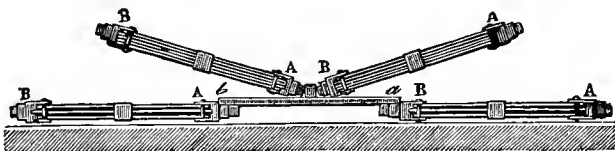


Fig. 682

FIG. 50.—MAGNETISATION BY DIVIDED TOUCH

ends, the magnets are returned through the air, again placed at the centre of the bar and the same motion continued a number of times. The bar is then turned and the other side subjected to similar movements. The magnetising bars may either be held vertically, or may be inclined. In this way, a much more uniform distribution of magnetism is produced than by single touch. The best results are obtained when the ends of the bar to be magnetised are rested on the poles of two separate magnets, as represented in Fig. 50.

In another method, known as “magnetisation by double touch,” two magnets are placed with their opposite poles

close together, but not touching, at the middle of the bar to be magnetised. Instead, however, of moving them in opposite directions towards the two ends of the bar, they are firmly fixed together and simultaneously moved first towards one end of the bar to be magnetised and then towards its other end, without removing them from the bar that is being magnetised. In order to obtain the best re-

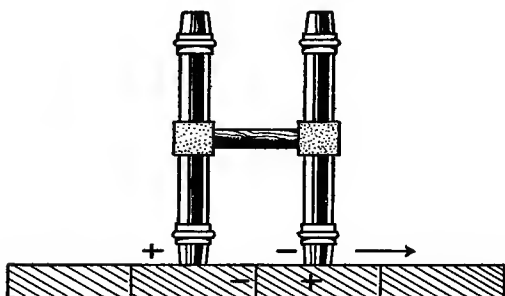


FIG. 51.—MAGNETISATION BY DOUBLE TOUCH

sults it is necessary to see that each half of the bar to be magnetised receives the same number of strokes; or, in other words, that the process be stopped when the two magnetising magnets are at the middle of the bar.

You can get a better idea of magnetisation by double touch by examining Fig. 51. In this method, instead of employing separate magnets in order to obtain the two opposite poles, a horseshoe magnet may be employed, the poles of which are brought rather closer together than usual. While the method of magnetisation by double touch produces powerful magnets, it is very apt to produce consequent points.

In the magnetisation of compass needles by the electric current, the needle is placed inside a hollow coil or solenoid, the length of which is preferably equal to, or slightly in excess of, the length of the needle that is to be magnetised. Bar magnets are also magnetised in this manner.

Fig. 52 represents a hollow coil suitable for magnetisation by electric currents. The coil is placed over a hole in the top of a table or other support. When the magnetising current is passing through the coil, the bar to be magnetised is passed up and down through the hollow coil an equal number of times.

It will be remembered that Knight constructed his famous magnetic battery for the purpose of magnetising

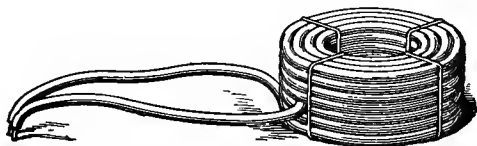


FIG. 52.—MAGNETISATION BY ELECTRIC CURRENTS

compass needles. This was done by placing the needles on the ends of the opposite magnet poles of two magnetic magazines, the needles being magnetised by a single touch; for it was only necessary to rest the needles for a moment on these poles to magnetise them to saturation.

As we have seen in one of the preceding chapters, bars of iron or steel are frequently magnetised by long contact with the earth; for the earth acts as a huge magnet.

Sometimes lightning discharges passing through bars of iron or steel permanently magnetise them. In such cases, of course, the magnetisation is due to the magnetic

flux produced around the circuits through which an electric current is flowing. In such cases, where the bars are of hardened iron or steel, the magnetisation is permanent.

In a similar manner, lightning discharges passing in the neighbourhood of compass needles may either completely demagnetise them, or may reverse their magnetism. Such a thing occurring to the compass needles of a ship, might easily cause serious losses.

There are some curious phenomena connected with the magnetisation of hardened steel or iron by lightning flashes. A lightning flash differs in no respect from the discharge of a Leyden jar battery except in its strength. Early in the history of magnetic science, while Arago, Davy and others were permanently magnetising hardened needles of steel by placing them in the hollow coils of the solenoids, and passing the current from a voltaic battery through the coils, a trial was made to see whether the discharge from a Leyden-jar battery could be employed in place of the voltaic battery. The experiment was tried and the bar was found to be magnetised apparently in the same way as it would have been had a steady or constant current from a voltaic battery been employed. When, however, this bar was more carefully examined it was found, to the great surprise of those making the experiment, that the polarity was not the same from the outside to the inside of the bar. On the contrary, there had been produced alternate layers of opposite magnetism at different distances from their surfaces.

This discovery greatly puzzled scientific men. They tried, and for a long time unsuccessfully, to explain this curious variety of magnetisation. It was because they were

unable to explain it that they called it anomalous magnetisation and the magnet so produced an anomalous magnet. As you will remember, this name has already been given to magnets that apparently possess three, five, or any number of odd magnet poles greater than one. I think it would be better if the name anomalous magnet were restricted to a magnet produced by a Leyden jar discharge and the magnet containing three, five, etc., odd poles were called a magnet with consequent poles.

In 1842, long after the above experiments were made, Professor Henry, already referred to, pointed out the cause for the peculiar magnetisation produced by Leyden jar discharges. He showed that the discharge of a Leyden jar, like that of a lightning flash, instead of continuing to pass in one and the same direction, like the current from a voltaic battery, rapidly changes its direction a very great number of times a minute, first flowing in one direction and then in the opposite direction. Of course, this would result in the magnetising current flowing in different directions through the magnetising helix, say first from the top to the bottom, and then from the bottom to the top, so that at one moment a north magnetic polarity would be produced, and at the next moment a south magnetic polarity at the same end. Instead, therefore, of a single magnetic pole being produced at the end of a needle, there would be a number of thin shells of opposite magnetic polarities, as they were actually discovered to be, either by carefully turning off or by eating away one shell by acids, until the next shell was reached.

No little excitement was produced in the year 1813 by the assertion made by Morichini, that if a steel needle is

merely exposed to the violet rays of the sun, the needle was thereby magnetised. A Mrs. Mary Somerville, who had written a book on natural philosophy, claimed that she repeated these experiments and succeeded in permanently magnetising a steel needle by exposure to the violet light of the sun for a period of two hours.

It may be interesting if I quote what Playfair says concerning this experiment:

“The violet light was obtained in the usual manner, by means of a common prism, and was collected into a focus by a lens of sufficient size. The needle was made of soft wire, and was found, upon trial, to possess neither polarity nor any power of attracting iron filings. It was fixed horizontally upon a support, by means of wax, and in such a direction as to cut the magnetic meridian at right angles. The focus of violet rays was carried slowly along the needle, proceeding from the centre towards one of the extremities, care being taken never to go back in the same direction, and never to touch the other half of the needle. At the end of half an hour after the needle had been exposed to the action of the violet rays, it was carefully examined, and it had acquired neither polarity nor any force of attraction, but after continuing the operation twenty-five minutes longer, when it was taken off and placed on its pivot, it traversed with great alacrity, and settled in the direction of the magnetical meridian, with the end over which the rays had passed turned to the north. It also attracted and suspended a fringe of iron filings. The extremity of the needle that was exposed to the action of the violet rays repelled the north pole of a compass needle. This effect was so distinctly marked as

to leave no doubt in the minds of those who were present that the needle had received its magnetism from the action of the violet rays."

It seems that there must have been some mistake in these experiments; for, when such able experimenters as Michael Faraday and Sir Humphrey Davy went to Italy the next year and repeated the experiment in Morichini's laboratory, they were unable to magnetise a needle.

In connection with magnetisation, it may be interesting to note that when a bar of iron is suddenly magnetised a change occurs in its length. While this may seem astonishing, yet a little thought would seem to show that it should be expected, since, if the very small magnets of which an unmagnetised bar consists are longer in one direction than in another, necessarily the turning around of these small magnets, so as to cause them all to point in the same direction, must cause a change of length.

If you would like to surprise some of your friends by invisible writing of a wonderful character, obtain a thin sheet of hardened steel, which you might get from the manufacturers of steel pens. Then take your magic wand, the blade of your penknife, or, since this experiment requires a rather stronger magnet pole, bring either pole of a bar magnet in contact with the surface of the steel plate and slowly write on it any word, say your name. You will then magnetise the plate wherever you touch it with the bar, so that a permanent record will be left on it wherever the magnet pole has been moved over it. You cannot see the writing, nor can your friends, but if iron filings be sprinkled over the plate, they will collect on the portions that have been magnetised, so that, if you after-

wards tip the plate and at the same time strike it gently with a lead pencil so as to get rid of the surplus filings, the writing can be distinctly seen by the collection of filings that remain clinging to the magnetised portions.

As we shall see in a subsequent chapter, "The Talking Newspaper," a somewhat similar method is employed for permanently recording on a wire or ribbon of hardened steel the message received by a telephone.

CHAPTER XVII

HOW THE FLUX CAN BE STRENGTHENED AND RETAINED IN MAGNETS

BUT the power of permanent steel magnets is greatly increased by placing separate pieces of soft iron or steel, called "pole pieces," in contact with each pole. Pole pieces may, therefore, be regarded as the soft iron or steel prolongations of the poles. Armatures or keepers consist of a single piece of soft iron or steel placed near or across the two poles and capable of motion towards them, so as to come in contact with both of them.

Armatures are sometimes formed of hardened steel. When made of soft iron or soft steel, they are called "non-polarised armatures." If made of hard iron or steel, they are called "polarised armatures," or armatures that possess a polarity independent of that imparted to them by an electric current flowing through the magnetising coils of the magnet near whose poles they are placed.

An armature is sometimes incorrectly called a keeper. But an armature is a keeper only under certain circumstances. There is always a tendency for a magnetised bar of hardened steel to lose its magnetisation gradually, and a keeper is employed only in order to prevent this loss. Now, while an armature, as long as it is in contact with the magnet poles, does the same thing and can, in this sense, be called a keeper, yet an armature has other work to do. It must be so placed that it can move towards or from the

magnet poles, in which case it is entirely different from a keeper.

Pole-pieces are employed for the purpose of increasing the strength of the magnet to whose poles they are permanently fixed. They are of especial use in compound magnets, which, as you remember, consist of numerous separately magnetised pieces of steel.

Pole-pieces, keepers and armatures, therefore, possess different properties. But there is one respect in which they agree: they all tend greatly to increase the amount of magnetic flux that is blown out from the north pole of the magnet, and sucked into its south pole.

I have frequently called your attention to the marked increase in the amount of magnetic flux that passes through a magnetic circuit on the introduction into it of soft iron or soft steel. This is especially marked in the case of a magnetic solenoid when a bar of soft iron or steel is placed inside it. Since the cause of the increase is the same in solenoids as it is in magnets, I will explain the matter to you by taking the case of a magnetic solenoid that has within its hollow coils a mass of air or, what is the same thing, a mass of wood; for, as far as magnetic flux is concerned, wood acts practically the same as does air. Afterwards, this wood is replaced by a core of soft iron of the same size and dimensions as the wooden core.

Suppose a wooden ring is uniformly wrapped with a coil of insulated wire, and an electric current is caused to flow through this coil. Magnetic flux will be set up within the interior of the ring, and will flow through it in parallel streams. All this flux is confined to the interior of the ring. If now another ring, of precisely the same di-

mensions, be wrapped with precisely the same kind of wire and the same number of turns, but over a core of very soft iron instead of wood, and the same electric current is caused to flow through the coils, parallel streams of magnetic flux will flow through the interior of the iron core just as they flowed through the wood core. There is, however, this difference: that, provided it is made of very fine soft iron, the amount of magnetic flux in the iron core will be, perhaps, as much as 1000 times greater than in the wood.

This is certainly wonderful. It seems at first almost impossible to explain, and, in point of fact, it has not been until a comparatively recent date that the true explanation was discovered. It is a difficult matter to understand, but I think I can explain it to you if you try your best to follow me.

Of course you know what causes magnetic flux to flow through the solenoid. It is the electric current flowing through the wire. Now in order to produce magnetic flux, there must exist a force called a magneto-motive-force; or, as we have agreed to abbreviate it, an M. M. F.

In the case of any magnetic circuit, the quantity of this flux that passes depends on two things; namely, on the value or strength of the M. M. F. and on the value of the magnetic resistance or reluctance of the circuit. In other words, the quantity of magnetic flux that passes through the inside of the electric solenoid will increase with the increase of the strength of the M. M. F. and with a decrease in the magnetic resistance of the circuit.

This being understood, let us consider the case of the two solenoids, one provided with a wooden core, and the

other with a core of soft iron. Since the current strength is the same in each, and the number of magnetising turns of wire is the same in each, the strength of the M. M. F. will be the same. Unless, therefore, the magnetic reluctance of the iron be different from that of the wood, the same amount of magnetism or flux must pass through each circuit.

Now it is well known that the magnetic reluctance or resistance of soft iron is much smaller than that of wood, so that when scientific men first thought about this matter, they came to the conclusion that a greater amount of magnetism flowed through a solenoid provided with a soft iron core than through one provided with a wooden core, because the soft iron core offered a smaller resistance and, therefore, permitted a given M. M. F. to force more flux through the iron; and for a long time this explanation was accepted as the true one.

For many years the scientific world was satisfied with the above explanation. Now, without wishing to ridicule the legal profession, for lawyers are generally able men, I may be forgiven if I point out to you that science is a somewhat different thing from law. Scientific men are not always satisfied with the truth of a statement because men regarded as authorities in science declare their belief as to its correctness. If I understand the matter correctly, this is different among lawyers; for, if a matter has once been what I believe the lawyers call adjudicated,—that is, has been passed on by some learned judge,—they feel that one of the strongest arguments they can use, if, indeed, not *the* strongest, is to call attention to this former decision, and if a number of decisions have been made in

the same direction, they regard the matter as practically settled, especially if an appeal has been taken against such a decision and the matter has been referred to some higher court, it may even be the Supreme Court of the land. A reference to such a decision is generally regarded as final. In other words, lawyers are apt to believe in what is called precedent. Now I wish to submit, with due respect to the bench, that this is not the kind of evidence a scientific man can properly regard as settling a question. If it were, scientific progress would be hopelessly barred in many directions.

I do not deny, however, that if an opinion has been expressed by an able scientific man as to the correctness of a certain explanation, such an opinion should be given due respect. Moreover, if this decision has been referred to some other scientific authority, the highest known at that time, or, as it were, the Supreme Court of that particular branch of science, and his decision has been to confirm that of the other authority, then one would be justified in leaning towards the ruling of the higher scientific court.

But no matter who may have ruled as to the correctness of a scientific principle, whether a lower or higher court, or even the Supreme Court, it will not do in science to follow that belief too closely. In physical science a thing is true, not because one or more authorities have declared they believe it to be true. It is only true because it *is* true, and herein I think a scientific man differs markedly from a lawyer. A scientific man is, as it were, a free lance, and, though willing to give due respect to authorities, he will never receive a statement as true because some other

one, even much better and greater than himself, has decided in its favour.

It was exactly this way with the world's belief as to why a given M. M. F. should cause more magnetism to flow through an iron circuit than through a circuit consisting entirely of air or wood. Up to a certain date, the decision by practically all the scientific courts had been that the increased magnetism that follows the introduction of soft iron into a magnetic circuit is due to the iron permitting more flux to flow because it offered a smaller resistance to its passage. At last, however, fortunately for the advance of science, one who might properly be called a kicker took up the question. Now, I have a great respect for kickers, at least when they kick intelligently. Much of the world's progress has resulted from this very valuable, though I think generally too little appreciated, class of people. One of this class, and he deserves great credit for what he did, noticed that, when the current flowing through the coils of the magnetic solenoid ceased to flow on the opening of the circuit, the magnetism of the iron core did not promptly disappear, as it should have done if the general belief had been correct. On the contrary, it remained in the core in the form of what is known as "residual magnetism."

Then our kicker began to get in his work. He reasoned, and, as I think you will see, reasoned correctly, that the decisions of the court in this case had been clearly wrong. If the great increase in the flux flowing through an iron core is caused only by the M. M. F. of the current flowing through the coils of the solenoid, then, as soon as this current ceases to flow, no magnetic flux should remain in

the core; for, if the flux were only set up by the electric current, how could it continue to exist when the current causing it ceased to flow?

Having come to this conclusion, which I may tell you is the correct conclusion, he properly determined to publish a statement of his belief. His friends came to him, urging him to bear in mind the eminent scientific men who declared that the old explanation was correct. But he published it, nevertheless, and the result was that, on carefully reading it, practically all scientific men came to the conclusion that the old explanation was wrong, so that in this case the decision of the Supreme Court was reversed.

You will say—at least I hope you will—“I can understand that, but was this all the man did? Did he only show that the old explanation was wrong? Did he also offer a better explanation?” He certainly did, and that is the point to which I am now coming.

It is evident, as I hope you can see, that in the case of a magnetic solenoid containing soft iron or steel, there must be two separate and distinct causes that set up or produce magnetic flux. One of them is the M. M. F. of the current flowing through the coil. Suppose we agree to call this the prime M. M. F. It increases with the increase of the strength of the electric current. The other was an M. M. F. that was set up, or, more correctly, set free, in the little molecular magnets of the iron or steel. These molecules are naturally magnetic. They have flux flowing through them that is due to a separate and distinct M. M. F. given to them when they are called into existence. But this natural M. M. F. was unable to produce any effect on the core so as to cause the magnetic flux to pour out

of the north end of the iron core and to enter it again at its south end. The streams of magnetic flux were confined to the circuit of the molecules and produced no effects on circuits lying outside of them.

Now under the influence of the prime M. M. F.—that is, of the M. M. F. produced by the electric current—all these little molecular magnets are turned or aligned so as to have their poles point in the same direction; *i. e.*, the length of the bar, so that there are set up a number of magnetic circuits parallel to each other and extending from one end of the bar to the other end. In this way, all their small M. M. F.'s are added, thus producing a separate and powerful M. M. F., which causes an increased quantity of flux to flow through the core. In order to distinguish this M. M. F. from the prime M. M. F. it is called the “aligned for structural M. M. F.”

You are now able to see how pole-pieces, keepers and armatures are able to increase the amount of magnetic flux that flows through a circuit.

Let us begin with the pole-pieces. Suppose we take for this purpose a magnetic battery, such as that of the compound horseshoe magnet of Jamin's, referred to in a preceding chapter. (Represented by Fig. No. 10.) These pole-pieces consist of fairly large and heavy masses of soft iron, so attached to the ends of the magnets as to leave no air-gap at the joints. The result was a marked increase in the amount of flux that passed through the circuit of the magnet. This, of course, must be so, since we now have besides the M. M. F. of the permanent magnet, which in this case may be regarded as a prime M. M. F., the very much stronger M. M. F. produced by the alignment of the

separate molecules of the soft iron of the pole-pieces. You can now understand why in a *Jamin horseshoe* magnet, consisting of three separate magnets only, the armature of the magnet that was only able to sustain a weight of 4 kilogrammes (8.82 pounds avoirdupois), without pole-pieces, was able to sustain a weight of 140 kilogrammes (308.8 pounds avoirdupois), when pole-pieces had been placed on the ends of the magnet.

The advantage gained by the use of a keeper or an armature of soft iron is the marked increase in the total amount of flux or magnetism passing through the magnetic circuit, as has been above explained.

When an armature of soft iron or steel is employed on an electro-magnet, the magnet will attract the armature no matter in what direction the current is made to flow through its magnetising coils. It makes no difference if the direction of the magnetising current is reversed; for the armature of soft iron or steel will have opposite poles set up in it by induction, no matter what the polarity of the poles may be. When the current flows through the magnetising coil, and the electro-magnet thereby acquires polarity, the armature is attracted, so that in order to enable this armature to do work, some device must be provided to pull the armature away from the poles as soon as the current ceases. The first opportunity you have in a telegraph station to see the working of the Morse sounder, you will be able to understand how this is done by means of a spring placed so as to pull the armature away from the magnet poles. When the operator depresses the key, so as to close the circuit and permit the electricity to flow through the coils of the electro-magnet in the sounder, the

strength of the magnetic attraction being greater than that of the spring, the armature is drawn towards the magnet, thus producing a clicking sound; while, as soon as the key is raised, and the circuit is thus broken, the electro-magnet loses its polarity and the spring pulls the armature back, thus producing another clicking sound. These clicking sounds following one another in different order and at different intervals produce the Morse characters or alphabet.

In some pieces of electrical apparatus, it is necessary to cause the armature to move either towards one side or another, or towards one pole or another, of an electro-magnet. In this case the armature differs from an ordinary armature in that it does not come to rest when touching both poles, but only when it comes in contact with the pole to which it had been attracted. The spring attached to the armature is adjusted so as to cause the armature to take up a position midway between the two poles when a weak current of a certain strength is passing. If, now, the strength of the current flowing through the electro-magnet is decreased, the armature will be pulled by the action of the spring against one of the poles, while if it is increased, it will be pulled by magnetic attraction towards the other pole.

But an armature can be caused to move towards either pole in a much better manner by the use of what is called a "polarised armature," or an armature that is magnetised independently of the electro-magnet. This armature is placed, as in the case of the armature above referred to, midway between the poles of an electro-magnet. When an electric current is sent through the coils of the

electro-magnet in a certain direction, its armature, being already magnetised, will move in a certain direction. While if the direction of the flow of current through the magnetising coil be reversed, it will move in the opposite direction. Such armatures are called polarised armatures.

As will be explained in "The Wonder Book of Electricity," polarised armatures are employed in systems of duplex and quadruplex telegraphy; that is, in systems of telegraphy called duplex telegraphy where two messages can be transmitted in opposite directions over a single wire at the same time, or in systems of telegraphy called quadruplex telegraphy where four separate messages, two in one direction and two in the opposite direction, can be transmitted simultaneously over a single wire.

CHAPTER XVIII

PARAMAGNETISM AND DIAMAGNETISM

THERE have been so many references to magnetic flux passing through iron and steel that I fear you may think these are almost the only substances through which flux is able to pass. Now, while it is true that magnetic flux passes through iron and steel far more readily than through other substances, yet there are very many other substances through which it can also pass. Indeed, as Faraday has proved, there are no substances through which some magnetic flux cannot pass, provided they are subjected to a very powerful flux. It follows, therefore, that there are no substances that cannot have magnetic poles produced in them, south poles at the place where the flux enters, north poles where it leaves them, although in most cases these poles are too weak to allow ready detection.

Faraday's discovery that magnetic flux can pass through all kinds of substances was a great achievement, and naturally attracted much attention in scientific circles in different parts of the world.

Faraday found that, if different substances were placed in a sufficiently powerful magnetic field, the flux passes through them; but they were not all affected in the same manner. On the contrary, they acted in a way that led him to divide them into two great classes. Before going any further, I wish to say that when I used the word substances in the above sentences, I do not wish you to understand me

as meaning solid substances only; for, Faraday found that not only all kinds of solid substances, but also all kinds of liquid or gaseous substances, when placed between the two poles of a powerful electro-magnet, either set themselves directly across such poles, as would a piece of iron, or in other words, were attracted to the poles; or they placed themselves midway between the poles in a line at right angles to the direction in which the flux was passing, as would a bar of bismuth. In other words, it seemed to Faraday that they acted as if they were repelled or driven away from the poles instead of being attracted.

Faraday, to resume, concluded that, as regards the action of magnetic flux, all substances could be divided into two classes; *i. e.*, those like iron, that are attracted, and those like bismuth, that are apparently repelled.

In order to examine this action of magnetism on different solid substances, Faraday cut the solid into slender needle-shaped pieces and suspended them by means of a delicate thread between the opposite poles of a powerful horseshoe magnet. When experimenting with liquid or gaseous substances, he placed the liquids or gases in small needle-shaped glass tubes similarly suspended. Now, in every case, as soon as the magnetic flux passed between the opposite poles of the horseshoe magnet, the needle-shaped pieces of solid substances, or the small cylindrical glass tubes filled with liquids, came to rest either when extended directly across the poles with their greatest length in the direction in which the flux was passing, or with their greatest length midway between the poles, or at right angles to the direction in which the flux was passing.

I think you will have no difficulty in seeing that, where

a needle-shaped substance came to rest, as would a needle of iron, directly across the poles or in the same direction as that in which the flux was passing, there was an undoubted magnetic attraction. The needle was pushed around by the invisible attendants of magnetism until it came to rest in such a position that the flux could enter in at its south pole and pass out at its north pole. Faraday called substances that would come to rest in this posi-

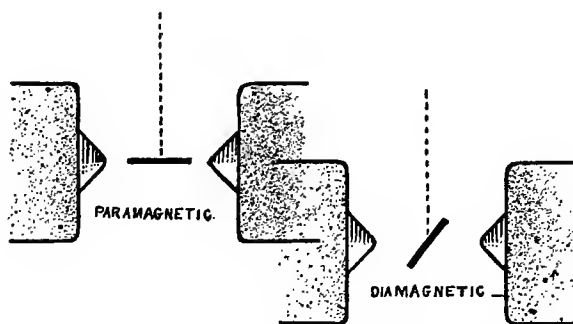


FIG. 53.—PARAMAGNETIC AND DIAMAGNETIC SUBSTANCES

tion “paramagnetic substances,” or substances that are magnetised like iron.

In the other class of substances, where the needle-shaped pieces came to rest with their greatest length midway between the poles or at right angles to the direction in which the magnetic flux was passing, instead of there being an attraction there was apparently a repulsion; for, as the flux passed through the substances, instead of producing a south pole where it entered and a north pole where it came out, it *seemed* to produce a north pole where it en-

tered and a south pole where it came out; for, the slender needle-shaped masses came to rest only when their poles had apparently been driven as far as possible from the inducing pole. Faraday called such substances "diamagnetic substances."

I am so desirous that there shall be no doubt about your understanding the different positions in which paramagnetic and the diamagnetic substances come to rest, when placed between the poles of a powerful horseshoe magnet, that I have shown in Fig. 53 the position assumed by a paramagnetic substance and that assumed by a diamagnetic substance. The apparatus actually employed in such experiments consists of a powerful electro-magnet with means for suspending between the poles the substances to be experimented on.

Since, as I have already explained, paramagnetic substances, when placed between two strong magnet poles, are attracted to the poles because of the unlike poles produced in them by magnetic induction, it was believed to be necessary to suppose that diamagnetic substances when similarly placed had like poles produced in them by induction and would, therefore, be repelled by the inducing poles. Indeed, Faraday assumed that diamagnetic substances possessed a polarity called "diamagnetic polarity" that was the reverse or opposite of ordinary or "paramagnetic polarity."

One wonders how so able a man as Faraday could have been willing for a moment to acknowledge the existence of a diamagnetic polarity; for, it necessitated a belief that, instead of the flux producing a south pole where it entered a substance and a north pole where it passed out of

it, in certain substances a north polarity was produced where the flux entered, and a south polarity where it came out. It would certainly seem there could be no reason why flux should act so differently in different kinds of matter.

In the following table you will find the names of some of the most important paramagnetic and diamagnetic substances arranged in the order of their relative strengths:

P a r a m a g n e t i c.

Iron
Nickel
Cobalt
Manganese
Chromium
Cerium
Titanium
Palladium
Osmium
Many ores of the above
metals
Oxygen gas
Liquid oxygen
Ozone

D i a m a g n e t i c.

Bismuth
Phosphorus
Antimony
Zinc
Tin
Cadmium
Mercury
Lead
Silver
Copper
Gold
Arsenic
Water
Alcohol
Selenium
Sulphur
Hydrogen

As you will see in the above table, iron, nickel, cobalt and manganese possess the most powerful paramagnetic properties, while bismuth, phosphorus, antimony, and zinc are among the most powerful diamagnetic substances.

You will notice that bismuth heads the list of diamagnetic substances. This was the substance in which the phenomenon of diamagnetism was first observed, long before the time of Faraday. What Faraday did was to show that all substances when placed between the poles of a magnet acted either as paramagnetic or diamagnetic substances.

Coming back to the matter of bismuth, I would say that in the year 1778, Brugmans of Leyden, while experimenting with a needle of bismuth suspended between the poles of an electro-magnet, observed that the bismuth was

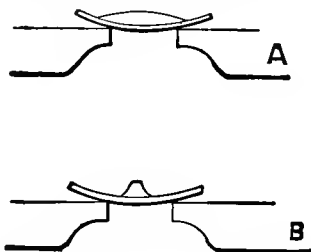


FIG. 54.—PARAMAGNETIC (A) AND DIAMAGNETIC (B) LIQUIDS

apparently repelled; and that at a much later date, 1827, the French physicist, Becquerel, obtained similar results with a mass of bismuth suspended in practically the same manner.

In the above table I have only mentioned the metals as diamagnetic substances. There are, of course, besides those named in the preceding table a great number of other substances that are also diamagnetic, such as rock crystal or quartz, alum, some varieties of glass, sulphur, sugar and bread. So also besides the paramagnetic substances named

in the table, there are many kinds of paper, sealing-wax, some kinds of glass, fluorspar, graphite, charcoal, etc. When, in order to determine the character of liquids, they were placed in glass tubes, in order to prevent the glass, which is sometimes paramagnetic and sometimes diamagnetic, from influencing the result, the tubes were made as thin as possible. Tests were also made with the empty tubes so as to determine the influence they would exert when filled.

Sometimes, however, instead of placing the liquids in tubes, they were placed in shallow watch crystals placed

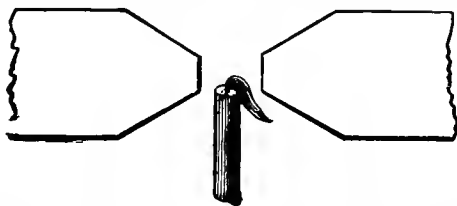


FIG. 55.—DIAMAGNETIC CHARACTER OF CANDLE FLAME

between the magnet poles as shown in Fig. 54. Under these circumstances, if the liquids were paramagnetic, such as are solutions of the salts of iron or cobalt, then on the passage of the electric current the mass instantly assumed a curious change in shape, placing itself in an elongated mass as if endeavouring to come to rest across the poles in the direction in which the flux was passing; or, as represented at A, in the above figure. If, however, the liquids were diamagnetic, the change in shape was such as to elongate the mass in the opposite direction, or so as to place the greatest amount of its mass at right angles to the direction of the magnetic flux.

Since most gases are invisible, when experimenting with gas it is necessary to make them visible by the admixture of a small quantity of smoke or iodine vapour. It is not necessary to place gases in glass tubes since, if no air is blowing between the magnet poles, gas issuing from a small orifice placed below the pole at a point midway between will rise in a thin, vertical stream.

Some exceedingly curious and wonderful results can be obtained with streams of gas flowing between opposite

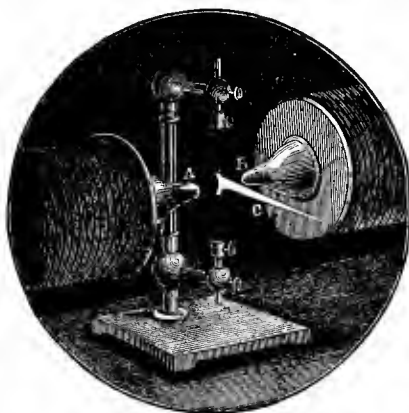


FIG. 56.—DAVY'S EXPERIMENT

magnet poles. For example, a candle flame consists of highly heated streams of gas containing red hot particles of carbon. If there is no air stirring in the room, the candle flame when permitted to burn between the magnet poles will point vertically upwards when no flux is passing, but when the magnetising circuit is closed, and the magnetic flux, therefore, is passing between the poles, a curious change instantly occurs in the shape of the candle flame.

One might think that the flame would be blown from the north towards the south pole by the magnetic flux as it is blown out of the north pole. But we must not forget that the flux which comes out of the north pole of a magnet is an exceedingly curious kind of material. It is weightless or imponderable, and, probably, consists of that very tenuous imponderable material before referred to as forming the luminiferous ether. As soon as the flux passes, the candle flame shows that it is diamagnetic by taking a position at right angles to the direction in which the flux is passing, or in the position shown in Fig. 55. Indeed, so violently does this change of position occur that if the magnetic flux is strong the candle flame will be instantly extinguished.

You have all seen the powerful electric arc lights that are employed for the illumination of the streets of our cities and towns. If you examine this light through a piece of smoked glass, you could see that, when the current is turned on, a luminous flame in the shape of an arc or bow is produced between two carbon rods placed near together. Now, this arc or bow consists of highly heated carbon vapour, and carbon vapour is a diamagnetic substance. It was shown by Sir Humphrey Davy that if a carbon arc is placed, as represented in Fig. 56, between powerful magnet poles, A and B, as soon as the flux passes, the voltaic arc or bow is suddenly increased greatly in length and is shot out at right angles to the direction in which the flux is passing, as shown at C. As you can see from examining this figure, the flux causes the voltaic arc to assume the appearance of a blowpipe. Indeed, an arc so deflected has actually been employed for the purpose of

fusing metals that only melt at exceedingly high temperatures.

At the present time scientific men no longer believe that there is any difference between paramagnetic substances and diamagnetic substances. In other words, there is no such thing as a diamagnetic polarity, the reverse of ordinary polarity. It is true that such distinguished scientific men as Weber in Germany and Tyndall in England were great believers in the existence of the diamagnetic polarity, and Tyndall, who has written a large book on diamagnetism, apparently continued to believe in its existence up to the time of his death.

It will interest you to know Faraday afterwards acknowledged his mistake, and agreed that there was no diamagnetic polarity.

Now you may say: "Did you not tell us that diamagnetic substances in the shape of needles came to rest between the poles of powerful electro-magnets in the direction in which the flux was passing, and that paramagnetic substances came to rest at right angles to this direction?"

Quite correct, and if you try to follow me I think I can explain why diamagnetic substances come to rest in a position at right angles to that in which the flux is passing and that this is by no means caused by repulsion.

A feeble magnetic substance, or let us say a substance possessing weak paramagnetic properties, if suspended between powerful magnet poles when surrounded by a paramagnetic liquid, acts as if it were actually diamagnetic. For example, a small glass tube filled with a weak solution of a certain salt of iron (ferric chloride), if suspended between powerful magnet poles, will come to rest in a

position at right angles to that in which the flux is passing; or, in other words, it is paramagnetic. If, however, it is surrounded by a stronger solution of the same salt, or by a solution that is more powerfully paramagnetic, it will point equatorially. Or, in other words, it will then be diamagnetic. This experiment, therefore, shows that when substances point at right angles to the direction in which the magnetic flux is passing, it does not prove they possess a diamagnetic polarity, but simply that they are less paramagnetic than the medium surrounding them. What has taken place is that, under the influence of the magnetic flux, this medium has come to rest with its greatest mass extending directly across the poles, and this has made the so-called diamagnetic substance appear to point at right angles to the direction in which the flux is passing.

Since oxygen is a paramagnetic substance, or a substance magnetic after the manner of iron, when a substance is suspended in the shape of a slender needle that is much less magnetic than the oxygen of the air, the air surrounding the needle will point directly across the poles and thus cause the needle to come to rest with its greatest length midway between the poles. But there is no repulsion. There is simply a stronger attraction of the opposite poles on the air magnet that extends between the poles of the electro-magnet.

When a needle of bismuth is suspended in air between opposite magnet poles, as soon as the flux passes, the air between the poles becomes by induction a strong air magnet. So, too, the flux which passes through the bismuth makes it a bismuth magnet. In both of these the point where the flux enters becomes a south pole, and where it

comes out, a north pole. But the induced polarity of the air magnet is so much stronger than that of the bismuth magnet that its poles are attracted and the two magnets are swung around so as to produce the least magnetic resistance in that part of the magnetic circuit lying between the poles. In order to do this the bismuth, which possesses an enormously greater magnetic resistance than the air, is placed with its least dimensions in the direction in which the flux is passing, or in other words, it is placed at right angles to the direction of the flux.

CHAPTER XIX

THREE PECULIARITIES OF THE EARTH'S MAGNETISM

WE, who are living in the beginning of the twentieth century, are, perhaps, apt to think too highly of our wonderful success in interpreting the laws of nature, and are, possibly, too prone to hug ourselves in delight at the great things that have been accomplished. And, indeed, to a certain extent, I am not sure but that we are justified in this self-conceit; for the achievements that may properly be called recent are certainly very wonderful. But we must not forget that all the great discoveries in physical science have by no means been made during the twentieth century, or, for the matter of that, during the nineteenth or eighteenth centuries. Indeed, one of the most wonderful generalisations in physical science was made near the close of the seventeenth century; *i. e.*, in 1690, by Dr. Gilbert, who wrote a wonderful book on magnetism that will be referred to in the last chapter of this Wonder Book. The generalisation to which I refer was that the entire earth acts as one huge magnet.

This, indeed, was a most important discovery. Once assured that our earth is a huge magnet, many things otherwise extremely difficult of explanation become almost matters of course. For example, the reason the compass needle points, approximately, to the earth's north and south becomes practically self-evident. It is due to the

attraction of the earth's opposite magnetic poles in the Northern and Southern Hemispheres. The natural lodestone magnets, found in the earth, or the bars of hardened steel, that have rested for many years on its surface, have become magnetised by induction from the earth. It is because our earth acts as a huge magnet, with its magnetic poles not exactly at the ends of the earth's axis but only in their neighbourhood, that compass needles point only approximately to the earth's north and south.

You remember the experiments made with iron filings scattered over the surface of glass plates resting on magnet poles in order to show the direction taken by the flux as it passes out of the north pole of a magnet into its south pole. I have often thought how wonderful a picture would be seen on the earth's surface, or more correctly, in the lower layers of its atmosphere, if both magnetic flux and the oxygen of the air were visible. Now, although both these things are invisible to the bodily eye, yet one might see them by the eye of the imagination. Let me, therefore, endeavour to show you this wonderful picture, as I would behold it, if I could get far enough from the earth to see one-half of its surface, and if I were at the same time able distinctly to see both the magnetic flux streamings and the almost innumerable molecules of oxygen scattered through the earth's atmosphere.

Out of the earth's north magnetic pole in the Southern Hemisphere I see a huge stream of magnetic flux blown with such force that it passes through the lower layers of the atmosphere until it reaches the earth's south magnetic pole in the Northern Hemisphere; and, on the supposition that I could also look through the earth, I see the flux

returning to the Southern Hemisphere where, again being blown out of the earth's north pole, it again completes the great magnetic circuit of the earth.

In this description I have limited the path of the earth's flux through its atmosphere to the lower layers. I have no doubt, however, that it passes practically through all the layers, but possibly with greater intensity in the case of those lying comparatively near the surface.

As to the arrangement of these magnetic streamings, as they pass from the Southern to the Northern Hemisphere, I imagine I can see that, although for the greater part they are almost equally distributed through the air, yet they by no means move directly towards the north. Nor are they everywhere horizontal or parallel to the earth's surface. They are variously inclined to one another. Moreover, in certain regions near the earth's surface, where the resistance to their passage has been decreased by the presence of large quantities of magnetic oxides of iron, or fairly great masses of metallic iron or steel, they crowd together in passing through these substances as if only too pleased to find a road that ensures easy travelling on account of the decreased resistance.

There are two kinds of places on the earth's surface where the flux streams are especially apt to crowd together. These are either where the huge skyscrapers or tall buildings have been placed with their great quantities of structural steel, or where the iron or steel rails of the railroad or trolley tracks have been laid. The flux streams are especially numerous where they pass through tracks that extend for great distances almost due north and south, such, for example, as the Cairo-to-Cape Railroad in Africa,

that extends from Cairo on the Mediterranean Sea almost uninterruptedly to the Cape, at the extreme southern part of the continent.

I regret it will be impossible fully to treat the subject of the earth's magnetism in so small a book as this. I will, therefore, take up some of the more important of its peculiarities only.

By far the most important property possessed by the magnetic flux that passes continuously between the earth's poles is its directive power, by which it causes the ends of a compass needle to point towards the earth's poles. It is this power that has permitted the mariner to find his way over the pathless ocean, and an almost continuous commerce to be carried on between all navigable ports of the world.

You cannot have failed to notice how careful I have been in speaking of the pointing of the compass needle always to say that it pointed "approximately" to the earth's north and south. It would point exactly to the true north and south if the magnetic poles of the earth were situated exactly at the ends of its axis, but since they are situated at some little distance from the geographical poles, the poles of the compass needle, except in a few places, point either to the east or the west of the true north. Generally speaking, people who have not given much study to the earth's magnetism believe that the compass needle points exactly to the north. They are apt to say, therefore, when they wish to find a figure for the constancy with which a certain thing occurs, that it is as "true as the needle to the pole star."

The two magnetic poles of the earth are situated at

points in the Northern and Southern Hemispheres at some distance from the ends of the earth's axis. Moreover, they are not situated at equal distances from the earth's geographical poles.

The magnetic pole in the earth's Northern Hemisphere has been accurately located; that in the Southern Hemisphere has only been approximately located.

Humboldt speaks as follows concerning the history of the discovery of the earth's magnetic poles: (In reading this quotation, it should be remembered that it was written during the time when the earth's magnetic north pole was regarded as being situated in the Northern Hemisphere, and its south magnetic pole as being situated in the Southern Hemisphere.)

“It is due to the bravery and scientific keenness of one single navigator that we know the exact position of these poles. Sir James Clark Ross determined the position of the north magnetic pole during the second expedition of his uncle, Sir John Ross, in 1829 to 1833. The south magnetic pole he determined during his own expedition to the Antarctic regions in 1839 to 1843.

“The north magnetic pole is situated about latitude $70^{\circ} 5'$ and $90^{\circ} 5'$ west longitude; being about five degrees more distant from the north geographical pole than the south magnetic pole is from the south geographical pole. The south magnetic pole is situated about latitude $75^{\circ} 5'$ and $151^{\circ} 48'$ east longitude. The longitudinal distance between the poles is 109° . The North Pole is situated in the Isle of Boothia Felix, near to the part of the American Continent called North Somerset by Captain Parry. It is situated a short distance from the west coast of the isle not far from

Cape Adelaide, which is between King William's Sea and Victoria Strait. The south magnetic pole has not been directly reached as the North Pole has. On February 17th, 1841, the *Erebus* was in latitude $76^{\circ} 12'$ south and $161^{\circ} 40'$ east longitude. The dip was then only $88^{\circ} 40'$, so that it was concluded that they were not more than 160 nautical miles from the south magnetic pole. A great many observations of declination made with extreme care to determine the intersection of the magnetic meridians lead to the supposition that the south magnetic pole is situated in the great Antarctic polar Continent South Victoria Land, to the west of the Albert Mountains, which include the active volcano Erebus, which is about 11,000 feet high."

It is quite possible that the magnetic poles of the earth are situated at somewhat different positions than those fixed by Ross, not only by reason of possible errors of observation, but also because the positions of such poles change slightly from time to time with the changes in the earth's magnetism.

This failure of the magnetic needle to point to the true north and south of the earth is called its "declination." You can remember this word by imagining the needle saying to itself, "I decline to point always to the true north and south, and, therefore, at times point to the east and west of these points."

The magnetic declination is said to be east or west according to whether the needle points to the east or west of the true geographical poles of the earth.

It appears that although, as we have seen, the compass needle was in use for many years, it was not until the time

of Columbus, in 1492, that it was actually known that in many places it does not point to the true north. The reason for this of course was that until the time of Columbus no navigator had gone very far from the part of the world in which he lived.

I can imagine how astonished the sailors of Columbus must have been when for the first time they noticed their compass needle was pointing so far from the North Star in the heavens, which, as you know, is practically always directly over the earth's north pole. The thought that the needle was losing its mysterious power of guiding them caused great alarm, especially since sailors, as a class, are exceedingly superstitious. Washington Irving gives the following description of the amazement occasioned by this fact:

“On the 13th of September, 1492, he (Columbus) perceived about nightfall that the needle, instead of pointing to the north star, varied about one-half a point, or between 5° and 6° , to the northwest, and still more on the following morning. Struck with this circumstance, he observed it attentively for three days, and found that the variation increased as he advanced. He at first made no mention of this phenomenon, knowing how ready his people were to take alarm; but it soon attracted the attention of the pilots, and filled them with consternation. It seemed as if the laws of nature were changing as they advanced, and that they were entering into another world, subject to unknown influences. They apprehended that the compass was about to lose its mysterious virtues; and, without this guide, what was to become of them in a vast and trackless ocean? Columbus tasked his science and ingenuity for reasons with

which to allay their terrors. He told them that the direction of the needle was not the polar star, but to some fixed and invisible point. The variation was caused not by any failing in the compass, but by the movement of the North Star itself, which, like the other heavenly bodies, had its changes and revolutions, and every day described a circle around the pole. The high opinion that the pilots entertained of Columbus as a profound astronomer gave weight to his theory, and their alarm subsided."

There are three peculiarities of the earth's magnetism that I wish especially to impress on your minds. The first relates to the failure of the magnetic needle to point to the earth's true north and south as above described. Now, since, as we have seen, a compass needle comes to rest only when it lies with its greatest length in the direction of the earth's flux, so that the flux can enter it at its south pole and pass out at its north pole, it is evident that the earth's flux does not extend due north and south in most parts of the regions between the north and south poles, although it is passing between them.

Another peculiarity of the compass needle that was first observed in 1576, by a practical London optician named Robert Norman, was that, if free to move in a vertical as well as in a horizontal direction, the compass needle would not only come to rest when pointing to the earth's poles, but, instead of remaining in a horizontal position, was in most parts of the earth's surface inclined towards the earth. It seems that Norman, who was an excellent workman and, therefore, properly took pride in making a good piece of work, was preparing an unusually long magnet as a compass needle. He did his best to so place the pivot

employed for its support that when resting on its suspension point it would assume a true horizontal position. Therefore, after adjusting and readjusting it, he at last succeeded in obtaining a needle that came to rest in an exact horizontal position.

But there was a great surprise in store for Norman. Having properly magnetised the needle and placed it on

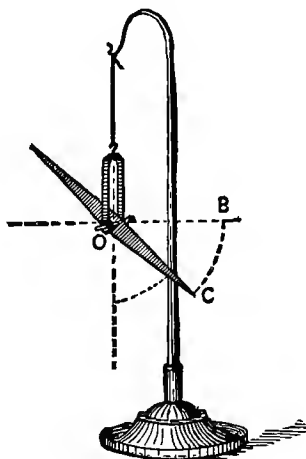


FIG. 57.—ANGLE OF MAGNETIC DIP

its vertical support, one end seemed heavier than the other. The north pole of the needle inclined or pointed towards the earth. Thinking that some mistake had been made and that, after all, the northern half of the needle was heavier than its southern half, Norman attempted to adjust it by cutting off a small part of the southern end. This, however, did not remove the difficulty, and at last he made so many changes in the needle that I am sorry to say,

unlike the philosopher he was, he lost his temper and broke the needle and threw it away.

Fortunately, both for Norman and physical science, he described the matter to one of his customers, an able physicist, who induced him to make a series of experiments. This was done and resulted in the discovery that the difficulty was not caused by any defects in the needle, but by a peculiarity in the earth's magnetism that had not before been observed. It was found that, when the needle is so suspended as to be free to move in a vertical as well as in a horizontal direction, its north pole would dip or incline towards the earth on almost all parts of its surface. This peculiarity is called the "dip" or "inclination" of the needle.

A second peculiarity, therefore, of the earth's magnetism is to be seen in the fact that a compass needle, when suspended so as to be able to move in a vertical as well as in a horizontal plane, inclines or dips towards the earth. In the earth's Northern Hemisphere it is the north pole of the needle that dips or inclines, and in its Southern Hemisphere it is the south magnetic pole that inclines.

The angle of magnetic dip or inclination is measured, as shown in Fig. 57, by the amount of its deviation from the horizontal line OB. If you are familiar with geometry, you can see that it is measured by the angle BOC.

The dipping needle, represented in the preceding figure, gives only a rough measurement of the value of the dip or inclination of the compass needle at different parts of the earth's surface. When it is desired to make more careful measurements a form of dipping needle invented by Biot is employed. The general appearance of this needle

is shown in Fig. 58. In its construction, as indeed in the construction of all magnetic instruments, it is necessary that no iron or steel be employed except that of the magnetised needle. All other parts must be made of some substance such as brass that is not readily magnetised, like the metals iron and steel. In the Biot needle the magnetic needle, *ba*, is suspended on knife edges in such a

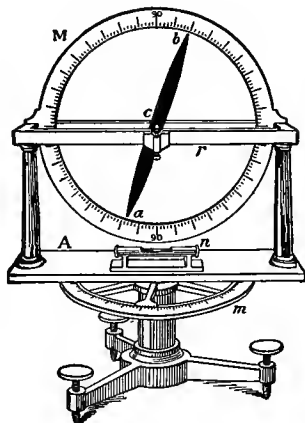


FIG. 58.—BIOT'S DIPPING NEEDLE

manner as to be able to move over a vertical circle, such as shown, that is graduated in each direction from a horizontal line from 0° to 90° in a vertical position.

A little thought will enable you to understand the causes of the dipping of the compass needle. There is no inclination or dip on the earth's magnetic equator; that is, on a line that extends around the earth everywhere equidistant between the earth's magnetic poles in the direction of the geographical equator. The amount of inclination increases

from the equator to the poles, the needle pointing vertically, downward or with an angle of inclination or dip of exactly 90° , when the needle is brought directly over either pole.

You will understand this better by an examination of Fig. 59. The circular line represents the earth, N, S its north and south poles; or, more correctly, the circle is a section of a wooden sphere that represents the earth, and N, S is a permanent magnet placed inside the sphere as

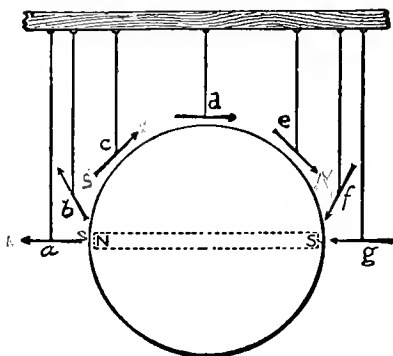


FIG. 59.—CAUSE OF MAGNETIC DECLINATION.

shown. Then, if a number of dipping needles, *a*, *b*, *c*, *d*, *e*, *f*, and *g*, be placed in different positions around the wooden sphere, their opposite poles will incline or dip towards the poles N, S, as shown. The needle *d*, which is on the magnetic equator, or exactly midway between the poles N, S, of course will show no dip, but will come to rest in a horizontal position, since the ends are equally attracted towards N and S respectively. The needles *a* and *g*, that are directly over the poles, will have an angle of dip of 90° , while the amount of dip in the remaining

needles will be greater the nearer they are to the poles of the earth; that is, the dip in the needles *b* and *f* will be greater than in the needles *c* and *e*.

But there is still another peculiarity of the earth's magnetism. If a compass needle that has come to rest with its north pole pointing approximately to the earth's north is moved out of this position for a short distance, it will, before again coming to rest, swing to-and-fro like a pendulum. Now if you count the number of oscillations or swings the needle makes at a certain part of the earth in a given time, say in a minute, and do the same at some other part of the earth, if these places are far enough apart, the chances are that the number of swings or oscillations will not be the same.

The following simple experiment, that you can easily make for yourself, will enable you to understand the cause of this peculiarity. Place a bar magnet in a horizontal position on any suitable support. Bring this compass needle within, say, half a foot of one of the poles of the bar magnet, and when it has come to rest pointing towards this pole move it out of its position of rest and carefully count the number of swings it makes in a given time, say one second.

Now move the compass needle nearer to the end of the bar magnet, and again count the number of oscillations the needle makes during the same time. You will find the number of oscillations to be greater than in the former case, and, moving it still nearer without, of course, permitting it to touch, you will find that the needle will make a greater number of oscillations in a given time, say a minute, or a quarter of a minute, the nearer it is to the magnet pole.

Without attempting to explain to you just why it is so, I can yet assure you that the number of oscillations the magnetic needle makes under these circumstances, like the number of oscillations a pendulum would make when under the influence of gravity, vary with the strength of the magnet pole near which the needle has been brought, just as the number of oscillations a pendulum makes in different parts of the earth varies with the difference in the force of gravity.

The strength of the earth's magnetism, therefore, varies at different parts of its surface, and since the intensity of a magnetic field at any point depends upon the amount of flux at that point, there must be a greater quantity of flux crowded in some portions of the earth's field than in others.

These three peculiarities of the earth's magnetism; *i. e.*, the magnetic declination, the magnetic inclination, and the magnetic intensity, are called the earth's "magnetic elements." In order to understand the peculiarities of the earth's magnetism, it is necessary carefully to study the distribution of its flux as regards these peculiarities: that is, the direction in which the needle points, the way the needle inclines or dips, and the number of oscillations it makes before coming to rest when disturbed at different points of the earth's surface.

CHAPTER XX

DISTRIBUTION OF THE EARTH'S MAGNETISM

IF you wish to observe the peculiarities of the earth's magnetism at any part of its surface, such as its intensity and the direction of its path as it passes out of the north magnetic pole in the Southern Hemisphere and enters the south magnetic pole in the Northern Hemisphere, it is only necessary to note the number of times the needle swings to-and-fro in a given time when it has been disturbed from a state of rest while pointing to the earth's magnetic pole, as well as changes in its declination or inclination; for the number of oscillations will tell whether the flux paths are crowded together or have moved away from one another, and the declination and inclination will show the path taken by the flux.

Now one of the most important discoveries ever made concerning the earth's magnetism is that its three magnetic elements do not possess the same values but vary to a greater or less extent from time to time. These variations can be divided into four distinct classes:

(1) Diurnal or daily variations that occur at different hours of the day or night.

(2) Annual or yearly variations that occur at different seasons of the year.

(3) Secular variations extending over many hundreds of years or those that occur during great cycles or periods of time.

(4) Irregular variations that accompany unusual out-

bursts of activity on the sun, or that occur at irregular intervals during the prevalence of auroras.

I will now tell you about the great discovery that was made concerning the four kinds of variations to which all the magnetic elements of the earth are subject.

The great physicist and traveller, Baron Alexander von Humboldt, suggested, in the year 1836, that an extended series of simultaneous magnetic observations be made over widely different parts of the earth. He persuaded the governments of the principal civilised nations to send out expeditions for the purpose of making such observations of the magnetic declination, inclination, and intensity as would enable them to obtain more accurate ideas as to these peculiarities of the earth's magnetism.

It was a great undertaking, and required the expenditure of large sums of money, such as great governments only are able to expend. In the first place it was necessary to send with each expedition a number of trained observers. Moreover, at each of these points it was necessary to build a magnetic observatory, and, since if such observatories have iron or steel anywhere in their construction the indications of their magnetic instruments would be affected thereby, giving false values for the declination, inclination and intensity, no iron or steel could be used in the construction of the building. Iron girders or beams were, therefore, necessarily ruled out. Even the use of iron hinges, bolts or locks for the doors, or nails or screws, were tabooed, materials like brass or similar substances being used in their stead. This greatly increased the expense. Then, moreover, after an observatory had been erected, the observers were naturally obliged to remain there for a long time, since, in

order to get true values of the magnetic declination, inclination, and intensity at any place, it is necessary to make observations extending over long periods of time. This again increased the expense; for even scientific men must be fed and clothed, kept warm and paid for their labours. All these things cannot be done without expending considerable money. Then, too, the apparatus costs something, less, perhaps, then than it would now, for the more recent apparatus employed for such observations is somewhat complicated. Nowadays magnetic needles automatically make permanent records of their to-and-fro movements on sheets of photographic paper that are accurately moved by expensive clockwork.

To give you some idea of the great extent of the work as thus planned and superintended by Humboldt, I would say that the expeditions were sent to and magnetic observatories erected at different places within the Arctic and Antarctic Circles, as well as in different parts of Africa, North and South America, on different islands of the Pacific Ocean and in various parts of India, Asia, Europe and Australia.

Extremely important results were obtained by these simultaneous observations, and much was learned concerning the peculiarities of the three elements of the earth's magnetism. But the most astonishing fact discovered was that every one of the four variations in the declination, the inclination, or intensity of the earth's magnetism that were observed at any one of these stations was simultaneously observed at practically all the other stations. In other words, the diurnal, annual, secular, or irregular variations occurred simultaneously over all parts of the earth, thus

showing the wonderful connection and coincidence of the causes producing the magnetism of the earth.

Of course this was only what might have been expected; for, if the earth acts as a single huge magnet, then, necessarily, a disturbance either in the direction or amount of its magnetic flux at any point on its surface must affect the distribution and quantity of flux in all other parts of its surface.

Let us now examine some of the variations in the three elements of the earth's magnetism.

First, as to the diurnal or daily variations. It has been observed, in certain parts of the earth, that between eight and nine o'clock in the morning the north pole of the compass needle begins to move slowly towards the west and continues this motion until about noon, when it begins moving in the opposite direction, or towards the east. The total amount of range of this motion is small, being only about the sixth of a degree. These diurnal variations of the needle appear to have been first observed in the year 1722 by a London optician named Graham.

The annual variations of the compass needle were first observed in the year 1780, by Cassini. These variations were also quite small in value. They are greatest, however, in the Northern Hemisphere in March, at the time of the vernal equinox, when the sun is shining vertically on the equator; and least, about June 20th, the time of the summer solstice, when the sun's rays fall vertically on the Tropic of Cancer.

The secular variations of the needle are those in which the compass needle during greater periods of time fails to point to the earth's true north and south.

Of course you can understand that, since the secular variations occur so slowly, it is necessary to compare the value of a great number of different observations made during many different years. A single case will be sufficient to explain what is done. Observations have been made in the city of Paris since the year 1580 as to the exact value of the declination of the magnetic needle. During this year the north pole of the compass needle pointed $11^{\circ} 30'$ east of the true north. The needle then began to move slowly towards the north, until the year 1663, when it pointed due north and south. In other words, during the year 1663 there was no magnetic declination at Paris, but after this year the needle began to move towards the west, and, continuing this motion, its declination during the year 1700 was $8^{\circ} 10'$ west; during the year 1780, its declination was $19^{\circ} 55'$ west, the needle moving further and further towards the west until the year 1814, when it reached its greatest western declination, and then began moving towards the east. The declination in 1825 was only $22^{\circ} 22'$ west; in 1865 it was $18^{\circ} 44'$ west, with the needle still moving nearer to the true north.

The irregular variations in the compass needle are due to a variety of causes, such as the appearance of an unusual number of spots on the sun, the prevalence of auroras, and even, it is claimed by some, the occurrence of volcanic eruptions. These irregular variations are sometimes known as "magnetic storms." As we shall see in a subsequent chapter on the aurora, the presence of electric currents in the atmosphere at these times would naturally produce variations in the magnetic flux of the earth, and thus result in variations in the compass needle.

It is an interesting fact that the presence of huge cyclonic or rotary storms in the highly heated gaseous atmosphere of the sun, by tearing away the luminous atmosphere and so permitting the relatively dark body of the sun to be seen through the opening as sun spots, is invariably followed by magnetic storms on the earth. This has been proved beyond any doubt by Wolf by means of a careful comparison of the times of occurrence of the appearances of spots on the sun and the prevalence of unusual magnetic storms on the earth between the years 1772 and 1880.

When, so as to prevent injury to the eyes by the intense light and heat, the body of the sun is observed through a telescope by the aid of properly screened glasses, the peculiar appearance the sun's atmosphere presents during the prevalence of a sun spot can be carefully studied.

The portion of the sun's surface that is ordinarily visible consists of a part called the "photosphere," a word meaning the sphere of light. When examined through a telescope of small magnifying power, the sun's disc appears darker at its edge than at the centre. The rest of the surface, however, is not uniformly bright, but is mottled, presenting somewhat the appearance of rough drawing paper. Now, during the prevalence of a sun-spot, the photosphere presents an appearance as if a great disturbance was taking place in the sun's luminous atmosphere. According to Professor Charles Young, from whom this description has been condensed, it appears probable that during this disturbance a whirling motion takes place in the photosphere, so that a hole or crater is produced through which one can look down on the relatively darker body of



A TYPICAL SUN-SPOT

The appearance of great spots on the sun is attended by marked disturbances in the earth's magnetic elements.
Drawn by Langley. (From Langley's "New Astronomy," published by Messrs. Houghton, Mifflin & Co.)

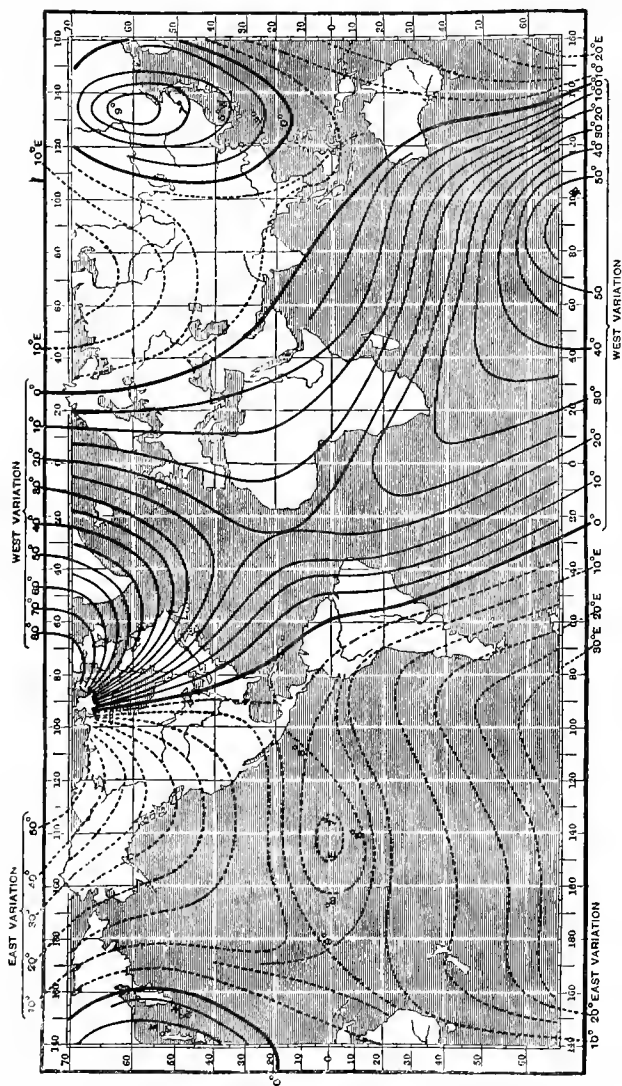


FIG. 60.—CHART OF MAGNETIC DECLINATION

the sun. These openings, or craters, vary in size from 500 to 50,000 miles, so that, as you can see, a sun-spot means a great disturbance in the sun's atmosphere.

In order to represent on a chart of the earth's surface the peculiar distribution of the earth's magnetic elements; *i. e.*, the magnetic declination, inclination, and intensity, lines called "isogonal lines," "isoclinal lines," and "isodynamic lines" are drawn.

I will now endeavour to explain to you the meaning of these words.

Isogonal lines are lines connecting places on the earth's surface where the magnetic declination is the same. The word isogonal means equal angles, and refers to the equal deviation of the compass needle to the east or west of the true north. Lines connecting places on the earth where the magnetic needle possesses no declination are called agones.

Isoclinal lines are lines connecting places on the earth's surface where the compass needle has the same dip or inclination. The word isoclinal means equal inclination.

Isodynamic lines are lines connecting places on the earth's surface where the magnetic intensity is the same. The word isodynamic means equal intensity.

Fig. 60 represents an isogonal or declination chart of the earth, on which the isogonal lines have been drawn. Here the agonic lines, or lines connecting places that have no declination, are represented by the heavy lines marked $0^{\circ} 0^{\circ}$. All places on the earth at which the magnetic declination is east is represented by dotted lines, and all whose declination is west, by the other continuous lines. The value of declination in degrees is marked as shown.

CHAPTER XXI

ATTEMPTS TO EXPLAIN THE CAUSE OF THE EARTH'S MAGNETISM

VARIOUS attempts have been made to explain the cause of the earth's magnetism. One of the earliest of these ascribed it to the presence of great masses of magnetic oxide of iron or lodestone in the crust.

To be satisfactory, any explanation of the earth's magnetism should not only be able to give the causes that produce the peculiar distribution of its magnetic declination, inclination, and intensity, but, at the same time, should also be able to account for the four kinds of variations to which each of these three elements is subject.

Perhaps the first question to be answered before attempting to give any explanation of the cause of the earth's magnetism is as to whether the magnetic poles of the earth are to be considered as lying below the earth's surface or above it. While the answer to this question is uncertain, Norman's discovery of the inclination or dip of the compass needle seemed to show that the poles are situated somewhere below the surface. It has, therefore, been asserted that the earth's magnetism is caused by the presence of immense quantities of permanently magnetised oxide of iron somewhere below the surface. Of course, unless some explanation can be given as to the cause of the variations in the declination, inclination or intensity of the earth's magnetism, such an explanation must be regarded as unsatisfactory.

When Gilbert suggested that the earth's magnetism is due to the presence of a sufficiently powerful magnet somewhere below the earth's surface, he also suggested, in order to account for the variations in declination, inclination and intensity, that since large portions of its surface consisted of bodies of water unaffected by magnetism, it might be that the compass needle pointed to different parts of the earth by reason of the difference in the attraction of the magnetised land masses. Of course the objection to this explanation is found in the fact that these variations exist over different portions of the earth's land surface as well as over the ocean.

One of the most curious of the explanations of the cause of the earth's magnetism is that of a man named Halley, who claimed that the secular variations of the earth are due to the presence in its interior of a huge magnet that is slowly rotating or spinning, and thus causing variations in the declination, the dip and the intensity. Halley employed the same explanation to account for the phenomena of the aurora; for, he said that there existed a huge cave or hollow space between that part of the earth's surface on which its soil rested and the interior, or the part undergoing rotation; that this hollow space was filled with a luminous matter, and that the aurora borealis is due to the escape of the luminous matter from the interior. But the most curious point about Halley's hypothesis was that this hollow space was inhabited by people something like ourselves.

Of course such a theory can only be regarded as ridiculous. If you will pardon me for digressing for a few moments I would like to call your attention to an interest-

ing book called "The Coming Race," in which the author has based his story on the assumed truth of Halley's hypothesis. The principal character in the story, while visiting a mine, unexpectedly slides down a huge chasm and reaches this illumined and inhabited interior without being seriously injured. He finds it inhabited by a people somewhat resembling the human race, only far more developed intellectually. They have so thoroughly studied the force that produces the illumination of their country, which the author calls the "vril force," and they have acquired wonderful power over it, and by the use of a device called a "vril staff," something like a staff or cane, only longer, are able by means of discharges of something closely resembling a lightning flash, to produce terrible effects on everything that comes in its path. He asserts that infants possess a greater command over this staff than do grown people.

You can understand that in a community in which each person is armed with so destructive a device as a vril staff, it would be impossible to compel anyone to obey the laws of the country, so that instead of saying to the people this or that *must* be done, the laws very politely suggested that the inhabitants were *requested* to do thus and thus. In this happy community, too, that very difficult question which troubles housekeepers so much had been completely solved because its inhabitants had discovered how to construct automata, or mechanical figures resembling men and women, which they could cause to move to-and-fro and perform all kinds of operations by means of vril force exerted at a distance.

Now I imagine you are surprised I should introduce

apparently such a ridiculous story. I acknowledge that it is ridiculous so far as the location of that particular community is concerned, for there are certainly no such regions below the earth's surface; but I am by no means sure that sometime, possibly during your lifetime, men may not acquire such a knowledge of the peculiarities of electricity and magnetism, that they will be able to perform at least some—if not, indeed, many—of these wonderful things that this people, it was claimed, could do by the agency of the vril force acting through their vril staffs.

By coming now to theories that are not so absurdly improbable as Halley's, I would say that the French physicist Biot suggested that, perhaps, the earth owes its magnetism to induction from the sun, which he claims is itself a powerful magnet. But it is improbable that the sun is a magnet, since its high temperature would almost certainly prevent it from acquiring magnetism. So far as we know, all magnetic substances lose their magnetism at exceedingly high temperatures. But the intensity of magnetism decreases with the square of the distance, so that even if the sun, despite its exceedingly high temperature, were a powerful magnet, it is situated so far from the earth, something in the neighbourhood of 92,970,000 miles, that its magnetism would be so weak when it reached the earth, that any magnetism it could give to the earth by induction would be too feeble to produce any marked effects.

A theory has been proposed by Ampère and others, in which the cause of the earth's magnetism is ascribed to currents of electricity flowing around the earth. This theory would seem to account for most of the peculiar facts of the earth's magnetism. It suggests that, if cur-

rents of electricity could by any means be caused to circulate around the earth from east to west, approximately parallel to the equator, the circular magnetic flux thereby set up would produce magnetic poles that would correspond generally to the magnetic poles of the earth. Moreover, it is well known that differences in temperature exist in different parts of the earth's crust, and that currents of electricity known as thermo-electric currents can be set up by these differences. Now, since the hottest portion of the earth at any particular moment is that receiving the vertical rays of the sun, and generally speaking, this hottest portion would be somewhere in the torrid zone either on the equator or north or south of the equator, according to the season of the year, then, as the earth rotated on its axis from west to east, an electric current would flow in an opposite direction around the earth from east to west. Now, according to Oersted's hypothesis, the direction of the circular flux that would be set up by such a current would be such as to produce a south magnetic pole in the earth's Northern Hemisphere and a north magnetic pole in its Southern Hemisphere. It would seem, therefore, that Ampère's theory is far from improbable.

Of course there is a difficulty as to how such a current could be set up in the water of the earth, since, as we know, the ocean occupies the greater portion of the surface at the equator. Still, the theory is in many respects far more probable than any that has as yet been proposed, so that, provided there is any way in which we could account for the presence of a sufficiently powerful electric current, this theory would appear to be able to account for the cause of the earth's magnetism.

There is a modification of Ampère's theory that might account for currents circulating around the earth from east to west: not, however, in its surface crust, but in the higher regions of the atmosphere far above its surface, where, on account of the rarefied air, its conducting power for electricity is fairly good.

What would seem to increase the probability of Ampère's theory is the fact that auroras which, as we shall show in a subsequent chapter, exert so undoubted an influence on the magnetic phenomena of the earth are now generally believed to be due to the passage of electric currents through a conducting mass of rare air that is situated far above the earth's surface.

It may interest you that in the year 1811 the Royal Danish Academy offered a prize for the best hypothesis to account for the earth's magnetism. This prize was won in 1819 by a physicist named Hansteen. Curiously enough, Hansteen's hypothesis is based on Halley's ridiculous theory, leaving out, I believe, both to the credit of Hansteen and of the Royal Danish Academy, the absurd belief in the existence of a habitable hollow region or space between the interior of the earth and its outer shell. Hansteen modified Halley's theory by supposing that there were four separate magnet poles in the earth instead of two. Since, however, no one now believes this explanation, it is unnecessary to discuss it any further.

Many other theories have been proposed to account for the earth's magnetism. While it does not seem that any of these are entirely satisfactory, yet I think there can be no doubt that the best theory is that there are electric currents flowing around the earth from east to west, either

through the crust or through the atmosphere. Of course, I acknowledge that there are serious objections to this theory, although I do not think that any of them are insuperable. Still it must be acknowledged that we can hardly regard the question of the true cause of the earth's magnetism as having been settled.

I think it may be well to close this chapter on the attempts to explain the causes of the earth's magnetism by the statement made by Lord Kelvin, formerly Sir William Thomson, in an address delivered in 1879. This is all the more interesting because I think no one will deny that, of all recent physicists, the late Lord Kelvin is to be regarded as the judge of the Supreme Court, and, although, as I have already pointed out, I would not accept a scientific statement because he made it, I nevertheless recognise that an opinion of his should receive great respect. Kelvin's statement referred to is as follows:

“As to terrestrial magnetism, of what its relation may be to perceptible electric manifestations we who are present know nothing. You all know that the earth acts as a great magnet. Gilbert, of Colchester, made that clear nearly 300 years ago; but how the earth acts as a great magnet—how it is a magnet—whether an electro-magnet in virtue of currents revolving around under the upper surface, or whether it is a magnet like a mass of steel or lodestone, we do not know. . . . What are called ‘magnetic storms’ are of not very frequent occurrence. In a magnetic storm the needle will often fly twenty minutes, thirty minutes, a degree, or even as much as two or three degrees sometimes, from its proper position—if I may use that term—its proper position for the time: that

is, the position which it might be expected to have at the time according to the statistics of previous observations. I speak of the needle in general. The ordinary observations of the horizontal needle show these phenomena. So does observation on the dip of the needle. So does observation on the total intensity of the terrestrial magnetic force. The three elements, deflection, dip, and total intensity, all vary every day with the ordinary diurnal variation, and irregularly with the magnetic storm. The magnetic storm is always associated with a visible phenomenon, which we call, habitually, electrical: aurora borealis, and, no doubt, also the aurora of the southern polar regions.

“We have the strongest possible reasons for believing that the aurora consists of electric currents, like the electric phenomena presented by currents of electricity through what are called vacuum tubes, through the space occupied by vacuums of different qualities in the well-known vacuum tubes. Of course the very expression, ‘vacuums of different qualities,’ is a contradiction in terms. It implies that there are small quantities of matter of different kinds left in those nearest approaches to a perfect vacuum which we can make.

“Now if we could have simultaneous observations of the underground currents, of the three magnetic elements, and of the aurora, we should have a mass of evidence from which, I believe, without fail, we ought to be able to conclude an answer more or less definite to the question I have put. Are we to look in the regions external to our atmosphere for the cause of the underground currents, or are

we to look under the earth for some unknown cause affecting terrestrial magnetism, and giving rise to an induction of those currents? The direction of the effects, if we can only observe those directions, will help us most materially to judge as to what answer should be give."

CHAPTER XXII

THE MARINER'S COMPASS

IN order to find his way across the ocean from one place to another, the mariner must know the direction in which he has been sailing, as well as the distance through which his vessel has passed. As to direction, he need only be able to see the sun by day, or the stars by night, in the absence of a clouded sky. But when the sky is obscured, so that the

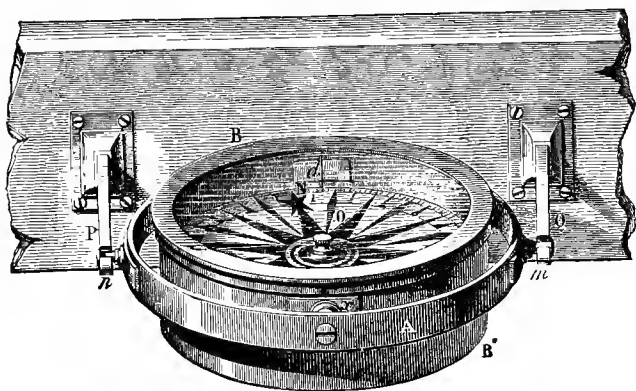


FIG. 61.—MARINER'S COMPASS

heavenly bodies are invisible, he can readily obtain this knowledge by noting the direction in which the compass needle is pointing. Indeed, even during clear weather, the compass needle is conveniently employed to determine direction. The amount of its declination, or failure to

point due north and south, is checked occasionally during clear nights by comparison with the North or Polar Star, in the Northern Hemisphere, or some star in the Southern Cross, in the Southern Hemisphere. As to the distance the vessel has passed through, it is only necessary to determine the speed of the vessel by means of the ship's log. Then, knowing both the distance and the direction, it is easy for the mariner to calculate his exact position on the ocean at any given time.

We have already explained why the compass needle points, approximately, to the earth's north, and have noted when the needle, or the mariner's compass, as it is now

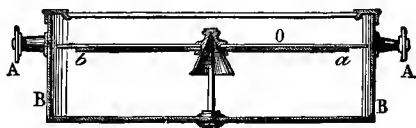


FIG. 62.—VERTICAL SECTION OF COMPASS

called, was first used on the sea for the guidance of sailors. It remains now to speak in detail of the construction of the mariner's compass, as well as to note some of the many difficulties that are apt to arise in the accurate use of this instrument.

The general construction of the mariner's compass may be seen from an examination of Figs. 61 and 62. Fig. 62 represents a vertical section of the preceding figure.

The magnetic needle, on which the operation of the mariner's compass depends, consists of a straight bar magnet, *ab*, Fig. 62, attached to the lower surface of a card, called the compass card. Where, as is frequently the case,

the compass card is illumined at night from below, the card consists of a sheet of mica, or other transparent substance, through which the light can pass. Sometimes, however, when the card is formed of thick paper, or other opaque substance, the light is placed so as to fall on the card from above. This card, as can be seen from the figure, is somewhat wider than the length of the needle, *ab*.

A star or rose, showing the direction of the points of the horizon, and provided with branches, is traced on the surface of the card. The point corresponding with the north pole of the needle is marked by a smaller star as shown.

The compass needle, or rather the compass card to which the needle is attached, is provided at its centre with a cup of agate or other hard mineral substance, and placed in a cylindrical copper basin, B, on a vertical needle point, supported as shown on the bottom of the basin.

The compass box is placed inside a box or closet called a "binnacle," in front of the helmsman near the stern of the vessel.

In modern vessels of great length, like the modern transatlantic steamers, it is more convenient to place the compass needle near the bow of the vessel.

Knowing the direction in which the vessel is to be steered, the helmsman turns the rudder by moving a wheel or in any other suitable way, until the direction of the needle coincides with the direction it is desired the vessel shall take. This he does by means of a sight vane placed above the compass, but not shown in the figure. The line of sight passes through a line, *d*, corresponding with the keel of the vessel.

It is necessary to provide means whereby the copper basin, in which the compass needle is placed, shall retain its horizontal position independently of the rolling of the vessel. This is done by the employment of a system of suspension called gimbals that consist of two concentric

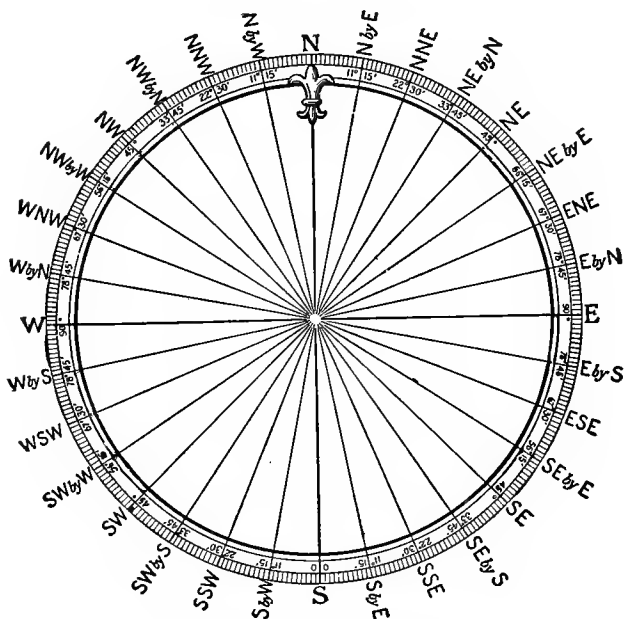


FIG. 63.—POINTS OF THE COMPASS

rings. These rings are fixed on two horizontal pivots to the circle which carries the box. The two axes on which the gimbals move are at right angles to each other, one, attached to the case itself, moving about the axis, *xd*, which plays in the outer ring, AB. This outer ring, in its turn,

moves on its supports, PQ, about an axis, $m n$, placed at right angles to the first axis.

This arrangement serves to keep the compass box in a level or horizontal position, no matter what may be the movement of the vessel.

A mariner's compass possesses greatest stability, or is best able to maintain a true horizontal position, when the copper cylindrical basin in which it is placed is provided with a heavy mass of lead at its bottom. Now this weight causes the compass box to fall rapidly into the desired position, on the same principle that operates the comical Christmas figures of jolly old men, clowns, or humpty-dumpties, that, instead of being supported on a flat base, are on a rounded base. Nor is it hard to understand how these figures operate; for, if the figure is moved out of an upright position, the weight is thereby raised, and, as soon as the figure is left to itself, the falling of the weight causes it again to assume its proper position. The same is true with the copper basin of the compass box. Here the rolling of the ship is unable to move the card out of its horizontal position without raising the copper weight, and if this is done, gravity soon brings the card again into its proper horizontal position.

The names and positions of the thirty-two points of the compass card are given in Fig. 63. Here, as will be seen, besides the names of the rhumbs or points, degrees are marked on the compass card, so that if desired the direction in which the vessel is moving can be given either in the rhumbs or in degrees.

You will find that as a rule sailors are apt to be proud of their ability to name from memory the thirty-two points

of the compass card in regular order around the entire circle. I will, therefore, give you these, since you may care to memorise them. If you do this, however, don't fail to learn them backwards as well as forwards; for, if you should learn them and repeat them successfully to a sailor, he would be sure to ask you to name them backwards. These points are as follows:

N.	E.	S.	W.
N. by E.	E. by S.	S. by W.	W. by N.
N. N. E.	E. S. E.	S. S. W.	W. N. W.
N. E. by N.	S. E. by E.	S. W. by S.	N. W. by W.
N. E.	S. E.	S. W.	N. W.
N. E. by E.	S. E. by S.	S. W. by W.	N. W. by N.
E. N. E.	S. S. E.	W. S. W.	N. N. W.
E. by N.	S. by E.	S. by S.	N. by W.

It is by no means as easy a matter, as many people think it is, safely to steer a vessel by means of a mariner's compass. In the first place, since there are comparatively few places on the earth's surface where the compass needle points due north and south, after the direction in which the vessel is sailing has been obtained by the needle, it is necessary to make a correction for the magnetic declination at that place, by adding or subtracting this declination according to its value. This, of course, is simple, and, were it the only difficulty, would not amount to much. Nor was it a very difficult matter to steer in the olden times, when ships were built of wood and contained but comparatively small quantities of iron or steel. In these days, however, when the entire ship is constructed of iron or steel, it becomes a huge floating magnet, so that, besides

the declination of the earth and the consequent deviation of the needle, there is a local deviation due both to the iron and steel of the ship itself, as well as to its boilers, steam engines, and other large pieces of machinery.

Of course it would be possible for a navigator by careful observation to determine, approximately, the value and direction of the local attraction caused by the ship as a magnet and then make an allowance as to the observed direction in which the compass needle is pointing in order to obtain the influence produced both by the declination of the earth and the local attraction of the ship. But, unfortunately, there are two other things that tend to increase the difficulty.

In the first place the magnetic material in the vessel consists of both soft iron or soft steel and hardened steel. The soft iron or soft steel instantly acquires a polarity opposite to that of the hemisphere in which the vessel may be sailing, while the hardened steel is apt to have acquired a permanent polarity according to the direction in which the vessel has been placed while being constructed. Now, while the magnetism due to the hardened steel tends to maintain its polarity, that produced in the soft iron or steel, by induction from the earth, instantly changes its polarity as soon as the vessel crosses the magnetic equator.

Any attempt, therefore, to correct the indications of the needle, by making allowances for the local deviation of the ship, is met by the difficulty that these deviations change in a most perplexing manner both as the ship crosses the equator and when it passes over portions of the ocean where the intensity of the earth's magnetism varies.

But even this is by no means the only, or, indeed, the greatest difficulty that has to be overcome in order to obtain the true direction of sailing by observations of the compass needle. The local variations produced by the ship are by no means of the same strength in no matter what direction the ship may be sailing. They produce their greatest effects when the magnetic axis of the ship, that is, a straight line joining the opposite poles of the ship regarded as a single magnet, extends in the same direction as that in which the ship is sailing. In other words, the magnetism of the ship produces the least disturbance of the compass needle when the ship is sailing in the same direction as that in which the magnetic flux of the earth is passing, and produces its greatest variation when sailing at right angles to this direction.

Of course, you can understand how serious a matter it is for even a slight mistake to be made in the supposed direction in which a vessel is sailing; for in many parts of the ocean trifling errors might readily result in the vessel being wrecked on a coast, or on some sunken rock. Many a noble vessel has been destroyed in this manner. A single instance of this will suffice to show you how very serious a loss might be occasioned. In 1854 the *Tayleur* sailed from Liverpool for Australia, on the 19th of January, with 528 people aboard. Her compasses had been carefully examined and did not show any material difference in direction. One was near the helmsman, and the other near the mizzen mast. Under the impression that the ship's compasses were pointing in another direction, the vessel was wrecked with a loss of 290 lives.

There are three different errors or variations in the di-

rection of the needle that may be caused by the local attraction of the iron or steel in a vessel:

(1) Errors due to the permanent magnetism of the vessel, making the entire ship act as a single bar magnet. This error is known among seamen as the "semicircular error," since it deflects the north pole of the needle in an easterly direction over an entire semicircle, and in a westerly direction over the remaining semicircle.

(2) Errors due to the magnetism of the soft iron of the ship, being regarded as a single bar, while under the influence of the earth's induction. This error is known among seamen as the "quadrantal error," since it acts to move the north pole of a compass needle towards the east in two quadrants or quarter circles, and to the west in the remaining two quadrants or quarter circles. Of course, as we have already stated, the amount of these changes will necessarily vary as the vessel crosses the magnetic equator.

(3) Errors due both to the soft iron and steel of the vessel as well as that of its hardened steel acting in a vertical plane. This error produces no effects in the direction of the ship's compass as long as the ship is riding on an even keel, but as soon as the ship heels over, under press of canvas, the position of the compass needle is influenced. This error is therefore called the "heeling error."

It is interesting to know that the permanent magnetism of the ship's steel is mainly determined by the position occupied by the ship while being built. According to Guillemin, a ship built with her head to the north has a permanent north pole developed in her mass of steel near the bow and a south pole near the stern.

Various devices are employed in order to overcome the local magnetism of the vessel, due to the magnetisation of the iron and steel used in its construction. One of these consists in placing a second compass needle aloft near the masthead, where it is subject to a much smaller error from the ship's magnetism than in the compass needles that are placed on its decks. Sometimes, permanent magnets are placed in various positions around the compass needle for the same purpose. But by far the best method for overcoming local attraction consists of masses of soft iron in the shape of two globes, a foot or more in diameter, placed on either side of the compass needle.

This most valuable invention was due to Professor Peter Barlow, an English physicist and scientist, who was born in Norwich, 1776. Barlow was Professor of Mathematics in the Royal Military Academy at Woolwich for forty years. He discovered that spheres or balls of soft iron, of the size above mentioned, when placed on either side of a compass needle, act exactly like miniature copies of the earth, by the induction of the earth's magnetism through them; that these globes, when placed in a certain position as regards the compass needle, protect it from being influenced by the magnetism of the ship, thus leaving the needle only under the direction of the earth's magnetism.

The globes of iron are called Barlow's globes. Barlow's invention may properly be regarded as a practical invention of almost inconceivable value. It is not wonderful, therefore, that the inventor received for this device marked recognition from various scientific societies in different parts of the world. Moreover, the English Board of Longitude awarded him a cash prize of £500 sterling (\$2500),

while the Emperor of Russia made him a present of a valuable watch and chain.

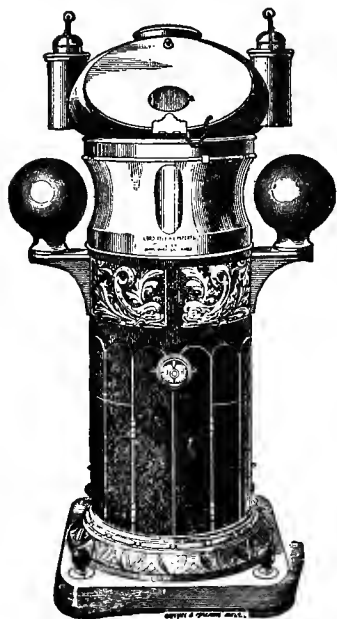


FIG. 64.—KELVIN'S BINNACLE,
WITH BARLOW'S GLOBES

A binnacle provided with Barlow's globes is known as a compensating binnacle. Fig. 64 represents a form of compensating binnacle devised by Lord Kelvin. This binnacle is provided, as shown, with two of Barlow's globes, placed on opposite sides of the instrument.

Various forms have been given to compass needles employed in the mariner's compass. Generally, instead of consisting of a single straight bar magnet, a number of separate magnets are employed for this purpose. The needles employed by

Lord Kelvin for this purpose consist of eight short steel wires that are separately magnetised and are then suspended side by side by a system of threads attached to the compass card.

CHAPTER XXIII

THE AURORAL LIGHT

THE aurora borealis, or the northern light, is the name given to a curious light seen at night in the heavens in the polar regions of the Northern Hemisphere. A similar light, seen in the heavens of the Southern Hemisphere, is called the aurora australis, or the southern light. The two phenomena are properly called auroras, meaning either the northern or the southern light. The plural is sometimes spelled auroræ, its Latin form; but the best authorities use the ordinary English form, "auroras."

An undoubted connection exists between auroras and magnetism. We will, therefore, describe their general appearance, and inquire especially into the causes that are generally believed to produce them.

According to recent investigations, both the northern and the southern lights generally appear simultaneously in each hemisphere; that is, when there is an auroral light in the Northern Hemisphere, there is, at the same time, one in the Southern Hemisphere.

The beginning of an aurora is accompanied by an appearance closely resembling the rising of the sun. Indeed, the word aurora means the morning or sunrise hour. When the phenomenon begins, the sky in the neighbourhood of the northern horizon begins to take on an appearance not unlike that seen at the break of day. A faint glow appears in this part of the heavens. Then ruddy tints appear that give to the northern heavens an appearance so closely re-

sembling a distant conflagration that in many instances an aurora has been mistaken for a fire. Towards the beginning of the phenomenon, a huge dark globe is seen in the heavens slowly rising above the horizon. Streamers begin to dart from its upper surface, causing it to resemble a huge rising sun, with, however, a dark body. The streamers, which soon begin to increase in luminous intensity, are of different colours, such as reddish, purplish, greenish or yellowish, and sometimes of a faint whitish light. The rounded segment, resembling a dark sun, is known as the auroral arch. The luminous streamers or rays appear to radiate from a point below the horizon, apparently coming from the arch and thus giving to it the appearance of a crown (or "corona," which is the Latin word for crown).

A well marked aurora is a glorious and at the same time a mysterious object. The gradual rising of the dark globe; the sudden flashing of crown-like rays from its upper surface; the curious and irregular manner in which these rays flash out from different portions of the globe, varying both in length and position, now suddenly appearing and as suddenly disappearing, together with their varying tints, especially their blood-red colours, cause the phenomena to appear as if due to the action of magic on a large scale. It is not surprising, therefore, that the ancients regarded auroras, not only with superstition, but also with no little dread. Indeed, even at a date as late as October, 1615, a writer claims to have observed in the heavens, during the prevalence of an aurora, "men of fire who fought in the sky with lances, and who, by their frightful spectacle, prognosticated the fury of the war which followed."

At a somewhat later date, September, 1755, in speaking

of two auroras that occurred in this year, one in February and one in September, a writer describes them as follows:

“The first appeared at about nine o’clock in the evening of February 13th, the other soon after sunset, at about seven, on the eve of St. Michael, September 28th. The first, by the order, the nature and variety of its forms, puts before our eyes a faithful picture of the calamities, vicissitudes, and all the strokes of fortune to which Flanders was soon exposed. . . . What did those two great wonderful arches mean? One towards the north seemed to come from the dark gulf whence came forth other arches and a great extent of light; the other, declining a little towards the south, representing Iris, by the different colours with which it was painted, extended from east to west, passing through the belt of Orion. The most northerly arch divided near Orion’s belt, and there issued a great quantity of rays, lances and inflamed swords; they disappeared with incredible rapidity; it was the image of a bloody combat.”

You will not, therefore, be surprised to learn that during the still earlier days of the ancient Greeks and Romans, the most extravagant ideas were attached to auroras. Seneca, in speaking of these curious luminous appearances in the sky, says:

“Amongst these we may notice what we frequently read of so often in history: the sky seemed to burn, the glow of which is occasionally so high that it may be seen even amongst the stars, and then slipping down so near the earth as to appear like a fire in the distance.”

Indeed, as already stated, auroras frequently resemble fires, so that, as an ancient writer says, “Under Tiberius

Cæsar, the cohorts ran to the help of the colony of Ostia, which was thought to be on fire, the sky glowing through a great part of the night, shining dimly like a vast and smoking fire."

It may interest you to know that during an aurora that occurred on the 24th of October, 1870, while Paris was besieged by the Germans, the reddish appearance assumed by the northern heavens near Paris gave rise to the belief that a great conflagration was going on in the besieged city. I will therefore quote you from Guillemin a description of this aurora, specially since it will give you a good idea of the appearances this class of phenomena sometimes assume.

"On Monday, October 24 (1870), about six o'clock in the evening, a ruddy glow arose from the northwest horizon. Little by little the glow spread, rising in the form of an immense arch, covering all the northern part of the sky from east to west. Suddenly, some brighter streamers of a pale red colour, furrowing across the darkest depths of the sky, removed all doubt as to the nature of the phenomena; it was a magnificent aurora.

"During the day the sky had been overcast with clouds brought up by a strong west wind, but towards evening it had cleared, and when the aurora began the stars were shining almost from one end of the sky to the other. The luminous arch continued to increase in brilliancy, and to expand until about eight o'clock, when it reached and crossed the zenith. The red tint was very vivid above and in the easterly and westerly horizons. In the north the colour was less marked, and beneath the luminous arch lay the dark segment often seen in auroras.

“Except the streamers, which here and there at irregular intervals crossed the base of the arch, and which were of a pale red or pale orange tint, the whole aurora was of a uniform ruddy colour. This colour, however, varied somewhat in tone; it was sometimes rose-red, at other times blood-red, and, again, of a deep crimson; but all through it was perfectly transparent, allowing even stars of the third and fourth magnitudes to be seen distinctly. The Great and Little Bears, Cassiopeia, Aldebaran, and the Pleiades, were all distinctly visible. At the moment when the arch reached the zenith the whole of its outer edge was bordered with a milk-white tint, resembling in colour the Milky Way, but much more regular and uniform. Then the display began to fade, though it was still visible after eleven o’clock. The greatest brilliancy was between eight and half-past.”

Guillemin thus describes the aurora of the following night:

“The luminous arch extended across the sky from east to west, but passed the zenith, extending into the southern skies. In the north, about 30° from the horizon, was seen a small red path of the same tint as the arch. Between the north and the west was a region of clear sky showing a faint greenish-white opalescence in strange contrast to the surrounding regions. As in the preceding aurora, many streams of a reddish hue shot up from time to time, but apparently not converging in any particular direction. One of these streamers, of a long, straight form and broad at its middle, was remarkable for the persistence of its position; it might have been taken for a cloud.

“Between seven and eight o’clock in the evening the

streamers presented a very curious appearance, worthy of being recorded. To the east of the constellations of Andromeda and Pegasus, at a point near the two second magnitude stars, there suddenly appeared two and then three small rose-white patches glowing like little luminous clouds or nebulae. These, while maintaining their general form, grew little by little in length, converging in three lines towards the point in question. Other rays of all sizes appeared one after the other in all directions, all of them converging to the same point in the heavens, giving the phenomena the appearance of a glory round the head of a saint."

It is a mistaken idea that the aurora borealis most frequently occurs in the immediate neighbourhood of the earth's north pole, but it is true that auroras are seldom seen outside the polar circle, and indeed seldom occur south of latitude 40° north.

Nordenskjold, the Arctic explorer, spent the winter of 1878-79 in Behring Strait on his vessel the *Vega* and had, therefore, an unusually good opportunity to study auroral phenomena. It happened that auroral displays were at that time unusually poor throughout the entire Arctic region. There were seen none of the more brilliant moving phenomena; no flashing streamers, auroral curtains, shimmering arches, but only feebly luminous halo-like arcs.

Nordenskjold's results are described by Guillemin:

"In consequence, however, of the absence of these extraordinary features, some very definite information was obtained about the simpler, less brilliant, and more ordinary auroral phenomena, which appear to persist around

the auroral pole. During that whole winter there was seen none of the brilliant and moving phenomena of coruscating arches, flashing streamers, coronæ or draperies. Instead of this, the aurora observed at Kolutchin Bay, in latitude $67^{\circ} 5'$ and longitude $186^{\circ} 37'$ E., was a simple, feebly luminous, halo-like arc, not distributed rays. Only once, on March 29th to 30th, did the explorers see any beams of light resembling streamers. The *common aurora arc* which they did see, whenever the sky was clear and dark, rose about 5° to 12° only above the horizon. It was often accompanied by one or more exterior arcs from which it was separated by a dark strip, sometimes crossed by rays of light flowing from one arc to the other. The exterior edge was not so well defined as the interior, within which lay the 'dark segment,' or, as Nordenskjöld prefers to call it, the 'unlighted segment,' of the sky. In one or two instances, when a low-lying cloud occupied this part of the sky, the light seemed to issue from the edge of the cloud. 'I can maintain with full certitude,' says Baron Nordenskjöld, 'that the lighted segment of clouds which we saw during the winter of 1878-79 had this origin, and, most probably, several luminous mists which we saw during the nights of March 18th and 20th, close by our ship, *close to the ice*, were due to the same cause; but I cannot affirm that quite certainly.' "

His observations led Nordenskjöld to the following conclusions concerning the polar aurora:

"Our globe, even during a minimum aurora year, is adorned with an almost constant crown of light, single, double, or multiple, whose inner edge was usually, during the winter of 1878-79, at a height of about 0.03 of the

radius of the earth (120 miles) above its surface, whose surface was somewhat under the earth's surface, having its centre a little north of the magnetic pole, and which, with a diameter of about 0.32 radius of the earth (about 1280 miles), extends in a plane perpendicular to the earth's radius, which passes through the centre of this 'luminous ring.' "

Of the two luminous rings of the "aurora-glory," as Nordenskjöld names it, the inner one, or *common arc*, is the most regular and almost permanent. But it is visible only in such parts of the Arctic regions as are not inhabited by people of European origin; a circumstance which, together with its feeble brilliancy, may account for the little attention it has received. The centre of the aurora-glory is situated about 81° N. lat. and 80° E. long., being a little north of the magnetic pole, and, as a matter of fact, more nearly coincident with the pole of greatest cold than with the magnetic pole. The outer ring of the aurora-glory is that which is sometimes seen in Sweden, and even in Great Britain, as a faint luminous arch. If the rays which were seen from the *Vega*, flowing from this ring to the zenith, were cast in the plane of the glory, they must have been visible over a circle of over 3,000 miles' radius, including California, England, France, and Europe generally as far as Hungary."

Although auroras present a great variety of different forms, so that, perhaps, no two are ever exactly alike, still there are certain characteristic appearances that generally occur; such, for example, as the streamers that flash out from the upper part of the dark segment. These are almost always characterised by sudden and erratic dancing

movements as they flash across the heavens; for the streamers not only vary considerably in length, darting at times almost to the zenith and at others contracting and growing so short that they finally disappear entirely below the edge of the dark segment, but also move across the horizon from east to west.

Sometimes the auroral light closely resembles a drifting mass of luminous snow that is being driven across the heavens generally in an east and west direction. At other times the appearance is presented of a series of parallel rays resembling a huge curtain suspended above the earth. The folds of the curtain instead of being stationary are ruffled as though blown by the wind. Such a curtain is called an auroral curtain and frequently possesses different colours from its lower end towards the top.

Although during dark nights the light of some auroras appears to be quite bright, yet generally speaking the light is quite feeble, so that the stars of the third and fourth magnitude can readily be seen directly through the light.

The parallel rays of light of which auroral curtains are formed, as well as the rays constituting the separate streamers, are, as already remarked, not stationary, but move rapidly to-and-fro.

Sometimes auroras present entirely different appearances from those just described. The rays or streamers are entirely absent, being replaced by a luminous appearance somewhat resembling the thin fleecy cirrus or curl clouds, commonly seen in the higher regions of the atmosphere. This form of light is called auroral vapours, and occurs spread in irregular patches and shapes over the sky.

Faint noises sometimes attend auroras. These noises

generally consist either of cracklings or buzzings, such as is well known are produced by a continuous discharge of electricity into the atmosphere from pointed conductors.

Guillemin speaks of these noises as follows:

“A very common opinion, not only among the inhabitants of Arctic regions, but also with some physicists, attributes to auroras a peculiar rustling noise, which the observers at Bossekop were not able to hear, in spite of the continued attention they gave to following the different phases of a great many auroras.

“Bravais thought that those who believed they heard this noise were deceived by several causes. ‘Such as,’ he says, ‘the whistling of the wind, the whirling of the snow, the distant murmur of the sea, the cracking of the snow, which congeals after having begun to melt, etc.’”

It would appear, however, that the aurora borealis is not always attended by noises, as the following quotation from a book entitled “Voyages in Scandinavia and Lapland” will show:

“M. Thomas, an engineer of mines at Kaaiford, declared he had seen the aurora between him and a mountain which he pointed out to me, but he had heard no noise. As to this alleged noise of the aurora, I cannot deny it, but there is at least reason to suspect that there is some illusion capable of easy explanation. In short, when one sees the whole sky covered with flames, as is the case in the most vivid auroras, when one watches these flickering lights, endowed with rapid movements, or the streamers forming for an instant and vanishing like rockets with amazing rapidity and sparkling with vivid light, it seems to me very natural that the spectator should be led into

error, so that, with all these appearances of fire, he should imagine that he hears the crackling of it, and applies to the sense of hearing what he has only learnt by sight. On the other hand, the possibility of a first illusion being granted, we know how easily an error is propagated by tradition, in spite of the witness of unprejudiced senses.

“Among those whom I questioned on this subject was an old man of seventy, to whom I owe many ideas on other questions relative to Finmark. This man, who was much occupied with agricultural experiments, and who had always observed with interest the state of the sky and the wind, had never heard a noise with the aurora. Accordingly the fact appears to me very doubtful.”

Notwithstanding the above opinion auroras *do* sometimes emit the faint sounds referred to, sounds that are generally characteristic of electric discharges.

There is no doubt that auroras are intimately connected with and are probably produced by the same causes that produce the earth's magnetism. This was suspected at comparatively early times. But the first proof that auroras are generally attended by variations of the earth's magnetic elements was not reached until the year 1750. I believe it was at a somewhat later date that Benjamin Franklin, the great American scientist, philosopher, politician, and poet, quaintly declared that auroras are due to “electrical fire discharged into the polar regions from perhaps thousands of leagues of vapourised air.”

All scientific men are now practically agreed that auroras are due to the passage of electrical discharges through the atmosphere at such distances above the earth's surface as to render the air electrically conducting. It is a well

known fact that when the terminals of an electrostatic machine, or of a Ruhmkorff coil, capable of producing electric sparks, are connected with conducting wires hermetically sealed in the end of vacuous glass tubes called Geissler tubes, the passage of the discharges through the tubes lights them up with a glow closely resembling the aurora. The colour of the light produced in this manner depends on the kind of gas that exists in a highly attenuated atmosphere inside the tube; for Geissler tubes are first filled with such gases as hydrogen, oxygen, nitrogen, carbonic acid, etc., and then exhausted, the colour of the light varying with the traces of the kind of gas that had been placed in the tube before their exhaustion. It is almost certain that auroras are caused in a somewhat similar manner by the passage of electrical discharges through the rare air in the higher regions of our atmosphere. Indeed, as has been suggested in the preceding chapter, if such discharges are actually present in the higher regions of the atmosphere, not only would auroras be produced, but the discharges would of necessity be accompanied by magnetic streamings or flux, first demonstrated by Oersted. In other words, such electric discharges would produce both the auroral light and the earth's magnetism. If this theory be true, then, since the earth is always a great magnet, it is evident that electric currents must be continually flowing through the upper regions of the atmosphere. Since, however, the auroral light is not always visible, it would seem that it is only when the discharges pass through certain portions of the air that they are able to produce luminous effects.

The electrical discharges which pass through the very

rare regions of the atmosphere and produce the aurora are probably at a distance of from 125 to 250 miles above the surface of the earth. This, according to various observations, is the height at which auroras most frequently occur.

One of the things a skilled telegraphic operator must be able to do is to adjust his apparatus so carefully that he can

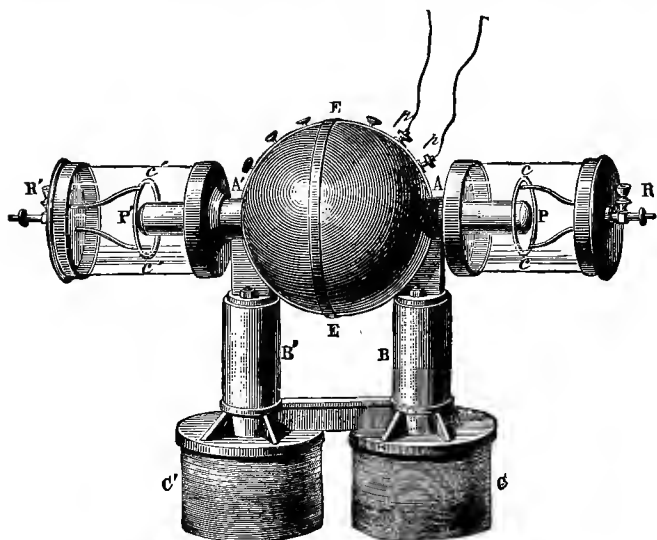


FIG. 65.—DE LA RIVE'S APPARATUS

vary the power of the springs they contain until they exactly suit the strength of the electric currents that are being passed over the line; for, in order to enable most telegraphic instruments properly to operate, the electric currents passing must as nearly as possible be of a constant strength.

De la Rive, the French philosopher, constructed a beautiful piece of apparatus to show how most of the phenomena of the aurora may be produced by the passage of electric discharges through vacuous spaces that are at the same time being traversed by magnetic flux.

De la Rive's apparatus is represented in Fig. 65. It consists of a wooden globe representing the earth, bearing at the extremities of its horizontal diameter two stems of soft iron, A P and A' P', resting on two vertical cylinders of soft iron, B B', that also support the sphere. These cylinders form the projecting poles of an electro-magnet, C C'. The stems of soft iron are surrounded by a glass cylinder hermetically sealed so as to be capable of sustaining a fairly high vacuum.

When in operation, the globe is caused to rotate on its horizontal diameter. When a series of electric discharges from a Ruhmkorff induction coil are passed between the iron stems P P' and the metallic rings C C and C' C', placed inside the rarefied globe, a lumious discharge occurs in the form of a jet between the rings and the soft iron stems. This is sometimes seen in one of the vacuous spaces, and sometimes in the other, but rarely in both at once.

De la Rive describes the action that occurs when the soft iron is magnetised and, therefore, the vacuous spaces between the soft iron stems and the rings are traversed both by magnetic flux and the electric discharges, as follows:

"As soon as the soft iron is magnetised the jet spreads out and forms round the central stem an arch, animated with a movement of rotation, the direction of which de-

pend on that of the magnetism. One important point to observe is that, if the air is not too much rarefied at the moment when, the soft iron stem being magnetised, the rotation begins, the jet not only spreads out into an arch, but brilliant rays are emitted, which, though perfectly distinct one from the other, turn like the spokes of a wheel with more or less rapidity.

“This is a fairly exact representation of what happens in the aurora borealis when the auroral arches, animated with a movement of rotation from west to east, dart luminous jets into the high regions of the atmosphere.

“The production of the jets only takes place when the soft iron is magnetised and it accompanies the movement of rotation; if the air is too much rarefied, it can be brought about by introducing there, drop by drop, a volatile liquid, water for example, which vapourises immediately.

“If now we turn to the galvanometer, where the two wires end, which come from the two neighbouring plates, placed on the moistened band that stretches like a meridian from one pole to the other, we observe a derived current, the direction and intensity of which vary, according as the discharge may be taking place at the pole which belongs to the hemisphere where the plates are placed, or to the other pole. We can also study very clearly the effect due to the secondary polarity which these plates acquire in transmitting the derived current; for that, it is only necessary to stop all discharge.

“By varying the conditions of the experiment you can reproduce in the movement of the galvanometer placed in the circuit of the conducting wire all the same variations

which constantly accompany the different phases through which the electric discharges of northern and southern auroras pass."

Now it has been noticed that whenever a great aurora exists in any part of the world telegraphic operators in the neighbourhood often experience considerable difficulty in maintaining the adjustment of their instruments, being obliged to change the strength of the springs frequently from time to time. Indeed, in many cases, the current passing over the wires varies so greatly that the operators can send no messages whatever. Now, since these currents are taken directly from the air by the telegraphic wires, it is evident that when auroras are occurring the air is charged with free electricity. Indeed, at times these charges are so marked that operators on long lines have frequently cut off their batteries completely and have telegraphed entirely by electricity collected from the atmosphere.

Noad, in his "Manual of Electricity," thus describes such a disturbance:

"The extraordinary influence of the *aurora borealis* on the needles, and sometimes even on the bells of the electric telegraph, is thus noticed by Mr. Walker, superintendent of the Electric Telegraphs to the South Eastern Railway Company, in his entertaining little work, entitled, 'Electric Telegraph Manipulation': 'At such times needles move just as if a good working current were pursuing its ordinary course along the wires; they are deflected this way or that, at times with a quick motion, and changing rapidly from side to side, many times in a few seconds, and at other times moving more slowly, and remaining deflected for many minutes with greater or less intensity,

their motions being inconstant and uncertain. These phenomena have occurred less frequently on the part of the line between Reigate and Dover, which runs nearly E. and W., than on the part between London and Reigate, which is nearly N. and S. When, however, they do make their appearance on the telegraph in those parts, we are prepared to expect auroral manifestations when the night arrives, and we are rarely disappointed. The deflections in their variations appear to coincide with the various phases of the aurora. On the branch line running from Ashford to Ramsgate, these deflections have been a much more common occurrence, even when the other parts of the line were unaffected, and when no auroral phenomena were noticed. This branch nearly coincides with the curve of *equal dip*. A dipping needle inclines downwards to the same angle $68^{\circ} 40'$ at all places along this curve; whether there is any relation between these two facts remains to be investigated. . . . The needles are also subject to feeble secular deflections, corresponding with certain hours of the day. The wires also at times collect electricity from the atmosphere, and affect the needles."

CHAPTER XXIV

THE GREAT TWIN BROTHERS

As you know, it sometimes happens that two children are born at a birth; one may be a boy and the other a girl, or two girls or two boys may be thus born. There may, therefore, be twin brothers, twin sisters, or a twin brother and sister.

Generally, but not always, there is such a close resemblance between twin children that people sometimes find it difficult to tell one from the other. I think it likely you may be acquainted with twins that thus closely resemble each other, especially if, as is generally the case, in order to make the resemblance more striking, they are purposely dressed exactly alike. It is on account of this resemblance between twin children that the word twin is frequently employed in the sense of a pair of things closely resembling each other; or of a double thing that consists of two similar or corresponding parts.

The great twin brothers, or more correctly speaking, the large family of twin brothers I intend to describe in this chapter of "The Wonder Book of Magnetism" cannot properly be regarded as twins because they resemble each other, but because they are necessarily born at nearly the same time. In point of fact they have no resemblances whatever so far as outward appearances are concerned. Indeed, they are so unlike that, so far from leading people to suppose that they are actually twins, although some of them have been in existence ever since the world began, it

was not until the 29th of August, 1831, that their close relationship was discovered.

Having now explained my meaning I take great pleasure in introducing to you magnetism and his twin brother electricity.

When I first wrote a list of the chapters that would form "The Wonder Book of Magnetism," I had selected for this chapter the heading, "Michael Faraday and His Great Discovery," but thinking the matter over and remembering that I had already a chapter entitled "Oersted and His Great Discovery," I changed the chapter heading to "The Great Twin Brothers," especially as I felt sure that this would impress on your minds the close relationship between magnetism and electricity.

You will remember that, in speaking of Oersted's discovery of the production of magnetism from electricity, I remarked that this was probably the greatest discovery ever made in magnetism. I think I would be also justified in saying that the discovery of the production of electricity from magnetism was the greatest discovery ever made in electricity. The great Michael Faraday was the discoverer. Just how and when Faraday did this I will now explain to you.

When I tell you just how this great discovery of the connection between magnetism and electricity was made you will see that it was analogous to that other great discovery made by Oersted of the close connection between electricity and magnetism. When I say that it was analogous, I mean that although there were many respects in which the two were entirely different, yet there were other respects in which there was an agreement or similarity

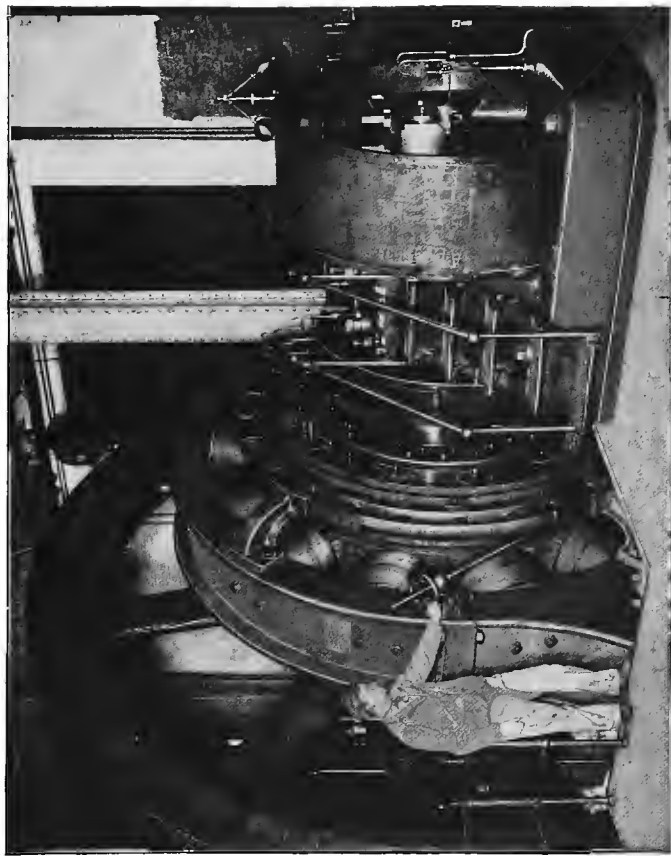
between them. You will understand this better when I compare the twin brothers with each other.

Oersted's discovery was that an electric current can never flow through a wire, or in fact any conductor, without circular lines of magnetic flux being born or produced, almost instantly, in planes at right angles to the direction of the current.

Faraday's discovery was that, whenever lines of magnetic flux are caused to cut or pass through conductors connected so as to form closed circuits, currents of electricity are produced.

But there is this difference between the two phenomena. Whereas an electric current can never flow through a conductor or circuit without giving birth to magnetic flux, magnetic flux can flow through a magnetic circuit without giving birth to electrical currents; for, unless there are electrical circuits properly placed with respect to the passage of the magnetic flux, currents of electricity are never produced.

Now, in using the phrase "The great twin brothers" as a chapter heading, I have had in mind a desire to bring prominently before you the fact that electricity and magnetism, or magnetism and electricity, I care not which, can properly be regarded as twin brothers, for the reason that the birth or production of one is invariably attended by the birth or the production of the other. The passage of an electric current through a conductor is instantly followed by the production of circular lines of magnetic flux around that conductor. In the case, therefore, of the production of magnetism from electricity, the birth of the twin brothers, electricity and magnetism, occurs at the



MODERN MULTIPOLAR DYNAMO

One of the many dynamo-electric-machines rendered possible by Faraday's great discovery of the production of electricity from magnetism.

By courtesy of "The Scientific American"

same time; that is, each are exactly of the same age. But when electricity is produced from magnetism, since it is only while the strength of an electric current passing through a conductor is rapidly increasing or decreasing, so that the circular lines of flux produced around the conductor, cut or thread through a neighbouring conductor, that electricity is thus born in that conductor, then electricity is slightly older than its twin brother magnetism, since a small fraction of a second is required for the flux to reach and pass through the conductor in which the electricity is born. But in each of the above cases, electricity and magnetism, or magnetism and electricity, are born at practically the same time, or are twin brothers.

Let us now see when and how the discovery of the production of electricity by magnetism was made. You remember that Oersted's great discovery of the production of magnetism by electricity was made towards the close of 1819. Faraday's analogous discovery of the production of electricity from magnetism was not made until the year 1831.

It was long suspected that some relationship existed between electricity and magnetism, but this relationship was only established by Oersted when he closed the circuit of an electric source and brought a portion of the conducting wire forming a part of this circuit over and in the immediate neighbourhood of a magnetic needle.

In a similar way, believing that the passage of electric flux should produce an electric current somewhere or somehow, but *how* he did not exactly know, Faraday began a series of experiments in which he caused magnetic flux to flow in various ways in the neighbourhood of electrical

conducting circuits. For a long time Faraday had no success. Indeed, if he had not known from long experience how extremely difficult it often is to be successful in a scientific investigation, he would probably have stopped experimenting in disgust long before he had reached any results.

But Faraday kept on experimenting, with all his senses on the alert to note the slightest hints telling him what to do. At last a faint hint came which set him on the right road. I am sure you will be interested in knowing just what this hint was, as well as what Faraday was doing when he received it. Faraday might have used a permanent magnet for the production of the flux from which he would cause an electric current to be born. In point of fact, however, at this particular time he was employing an electric current to produce magnetic flux just as Oersted had done, and he caused this electric flux to pass through another circuit and cause electric currents to be born or set up in it.

Suppose now, for the sake of convenience, we call the first of these circuits the primary circuit—*i. e.*, that through which the electric current is flowing, and thereby producing magnetic flux—and that in which the electric current is produced by the magnetic flux of the primary circuit, the secondary circuit. Faraday discovered that, no matter what position the wires of the primary and secondary circuits occupied as regards each other, he was never able, by causing an electric current to continue to flow through the primary circuit, to produce even the smallest current of electricity in the secondary circuit.

On one happy day, however, the 29th of August, 1831,

while his whole attention was directed to these two circuits, he noticed that, during the very short time existing between the moment he *made* or completed the primary circuit by closing the poles of a voltaic cell and the time required for the current to reach its full strength in this circuit, a slight movement occurred in the needle of a galvanometer he had placed in the secondary circuit to aid him in detecting the presence of a current flowing through it. The needle of the galvanometer moved from its position of rest when such a current was set up. He also noticed at the moment the primary circuit was opened, during the time the electricity from the voltaic battery was disappearing or dying out in the primary circuit, that a current of electricity was produced in the secondary circuit. But the current so produced was now evidently flowing in the opposite direction, for the galvanometer needle in the secondary circuit now moved in the opposite direction to what it did at the moment the current began to flow in the primary circuit.

Pondering no little as to the meaning of these phenomena, and remembering that while the strength of an electric current flowing through a conductor is increasing, the circular lines of magnetic force surrounding it increase in number and expand or move outward, and that, when the strength of such current is decreasing, the circular lines of flux contract or move inward, he saw that under these circumstances the flux cuts the conductors of the secondary circuit in one direction while increasing, and in the opposite direction while decreasing. It, therefore, occurred to him that the condition necessary to cause magnetic flux to produce electricity in the secondary circuit was to cause

it to pass across or cut its conductors. In this way another of nature's great secrets was discovered. An entirely new means for producing electricity was now made possible.

In order to permit an electric current to flow through a circuit, the circuit in which it is induced must be closed; that is, a continuous path must be provided for the induced current. In this sense, therefore, the secondary circuit can be regarded as consisting of a single loop; so, instead of saying Faraday discovered that, in order for the flux of the primary circuit to induce electricity in the sec-

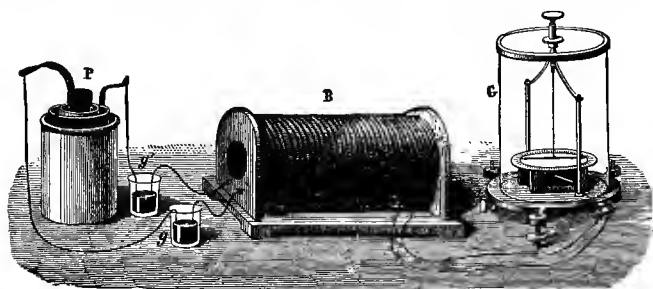


FIG. 66.—ELECTRO-DYNAMIC INDUCTION

ondary circuit, it must move so as to cut or cross the conductors of such circuit, we can say that the flux must be caused to thread or pass through the conducting loop of which such circuit may be regarded as consisting.

The production of electricity in this manner by causing magnetic flux to cut or pass through conducting circuits is called electro-dynamic induction. There are a number of different ways in which electric currents can be produced by electro-dynamic induction.

Suppose, as is represented in Fig. 66, that a hollow cylindrical spool, B, is wrapped with two insulated wires

placed side by side and constituting the primary and secondary circuits before referred to. Suppose, moreover, that the terminals or ends of the primary circuit or wire be connected with the terminals of a voltaic cell, P, through the two mercury cups, g and g' , and that the terminals of the secondary circuit be connected as shown with the coils of the galvanometer, G.

Now, while a constant electric current is flowing through the primary circuit from the voltaic cell P, the galvanometer needle remains at rest, thus showing the absence of any current in the secondary circuit. If, however, one of the terminals of the voltaic cell P be raised from the mercury cup g , thus breaking the circuit and causing the current strength in the primary circuit to suddenly fall from its full strength to nothing or zero, the needle of the galvanometer will be deflected in a certain direction, and the amount of this deflection will be greater the more suddenly the circuit has been opened.

This deflection of the galvanometer needle, however, is only momentary. As soon as the current has ceased to flow in the primary circuit the needle comes to rest, after swinging to-and-fro for a few moments, thus showing that the induced current is no longer flowing through the secondary circuit.

If, however, the current through the primary be again made to flow by inserting the wire of the voltaic cell in the mercury cup at g , the galvanometer needle is again deflected but now in the opposite direction.

I think you can now understand what has taken place in the apparatus represented in the above figure either on the opening or the closing of the primary circuit.

When the circuit through the primary was suddenly opened the magnetic flux that had been set up around the coils of wire in the primary circuit and had, therefore, spread through those coils, suddenly dying out, contracted and, moving closer to the primary wire, cut through the coils of the secondary, or threaded through the hollow helix in a certain direction, and *in* so doing, and only *while* so doing, induced an electric current in the secondary coils flowing in the direction indicated by the deflection of the needle of the galvanometer. In a similar way, when the circuit of the primary was again closed by dipping the wire in the mercury cup *g*, the magnetic flux around the primary coils increasing or expanding again cut through the coils of the secondary or threaded through the hollow helix in the opposite direction, and *while*, and *only while*, the current was increasing from nothing up to its full strength, or while the circular flux around the primary coils was increasing was the current produced.

The introduction of a soft iron core inside the hollow helix greatly increases the amount of magnetic flux passing and therefore greatly increases the strength of the current induced in the secondary circuit.

The preceding experiments show:

(1) That a current is induced in a secondary circuit either at the moment of the breaking of the primary circuit, or at the moment of closing that circuit.

(2) That the direction of the current induced in the secondary circuit on breaking the circuit in the primary is opposite to that induced on making that circuit.

(3) That the currents induced by the secondary circuit continue for very short periods of time; *i. e.*, only during

the time it takes the current to entirely cease on the opening of the circuit, or to reach its full strength on the closing of the circuit.

In order to produce currents by electro-dynamic induction, that is by Faraday's invention, the primary circuit is often opened and closed thousands of times in a minute. Currents so produced are called alternating currents because they flow in opposite or alternate directions through the circuits in which they are set up. When it is desired to change alternating electric currents into direct currents, or those that flow continually in the same direction, devices called commutators are employed. These will be described in "The Wonder Book of Electricity."

But it is not necessary to employ an electric circuit in order to produce the inducing magnetic flux. As we have already seen, flux is continually flowing out of the north pole of a magnet and constantly entering its south pole, so that if a magnet is moved past a conducting circuit, or a conducting circuit is moved past a magnet, there will be produced electric currents in that circuit.

If, for example, a bar magnet be thrust into a hollow coil, the ends of which are connected with a galvanometer, electric currents as shown by the deflection of the galvanometer needle will be set up in the coil, in one direction when the magnet is thrust into the coil, and in the opposite direction when it is drawn out of it. It can, moreover, be shown that the direction of these currents is what would have been produced by magnetic flux flowing in the direction in which, according to Ampère's theory of magnetism, it must flow in order to produce such a magnet pole.

It would seem, therefore, that we have not yet exhausted

all the wonderful magic that exists in your magnetised knife-blade; for, if you thrust an open blade into any hollow coil, it will produce electricity, and when you draw it out of the coil it will also produce electricity, but now in the opposite direction from that which resulted when it was thrust into the coil, and this you can continue to do without the knife losing any of its magnetism.

The great importance of Faraday's discovery of the production of electricity by magnetism will be better understood when I tell you it was this discovery that rendered possible the invention of the dynamo-electric machine, thus making it possible to produce those enormous currents of electricity that are employed every day in different parts of the world for lighting streets and houses at nights, for the driving of machinery, for the moving of trolley cars, or for the manufacture of the many products that are now produced by electric furnaces. It also led to the invention of the electric motor.

CHAPTER XXV

MAGNETISM AND LIGHT

THE discovery by Faraday of the relations between magnetism and electricity, when taken in connection with the discovery by Oersted of the relations between electricity and magnetism, practically brought these great branches of physics under a single head. It now remains to tell you how another discovery by Faraday, when taken in connection with the studies of two English physicists, Clerk Maxwell and Lord Kelvin, resulted in showing that such close relations exist between electricity, magnetism and light as to result in the creation of a new branch of physics called electro-optics, or more correctly, electromagneto-optics. Since these phenomena are connected with the flow of magnetism, as well as with the flow of electricity, they will be briefly discussed in this Wonder Book.

Faraday evidently gave considerable thought to Oersted's discoveries, as I shall prove to you. Before doing this, however, I must tell you that there are two entirely different conditions in which free electricity may exist; *i. e.*, as an electric charge and as an electric current. In order to be able to produce magnetism, electricity must be in motion. An electric charge, by which is meant free electricity in a state of rest, on the surface of an insulated conductor, is unable to produce magnetism. It is only when the electricity is moving or flowing—that is, when in the con-

dition of an electric current—that it is able to produce, as first observed by Oersted, the circular lines of flux in planes at right angles to the plane of the conductor.

Now, Faraday, who understood this thoroughly, argued that if a conductor possessing an electric charge were given a sufficiently rapid motion, it should acquire the properties



FIG. 67.—LUMINOUS BRUSH

of an electric current, and would, therefore, be able to produce magnetism.

It does not seem that Faraday ever made such an experiment, probably owing to want of time and the proper means for giving the charged conductor a sufficiently rapid motion. This, however, was afterwards done in 1876, by Rowland, an American physicist, who showed that a charged disc when rapidly rotated acquires the power of deflecting a magnetic needle as would a feeble electric current.

But there are much better ways of proving that a rapidly

moving charge acquires the properties of an electric current: ways that are both simpler and far more convincing. There are numerous instances where streams of electrified particles of matter thrown off from electrified surfaces at very high velocities are capable of acting like electric currents in being deflected by magnetism. As this is an important matter, and as wonderful effects are produced by such streams, I will describe some of the most interesting of them.

When a powerful frictional electric machine is operated in cold dry air, with its rubbers in good order, there can be seen in a darkened room faintly luminous brushes on the projecting portions of its conductors. If a large conducting plate is held before a pointed conductor connected with the positive conductor of the machine, and held at such a distance as will prevent the discharge from passing as a single spark, a brush, such as represented in Fig. 67, will be seen. This discharge consists of a short luminous stalk or stem with a great number of rays diverging, as represented, from the stalk, so as to give it the appearance of a luminous brush. The discharge is therefore known as the brush discharge. Wheatstone has shown that this discharge does not consist of a continuous discharge, as it appears, but of a great number of partial discharges that follow one another with great rapidity, thus producing a faint musical tone.

What especially interests us here in this form of electric brush discharge, is that it consists of streams of molecules of air together with exceedingly small particles of metal that have been *torn* from the conductor by the discharge. All these molecules and particles possess charges and move

with great rapidity as they are thrown off from the conductor. They should, therefore, be capable of acting as an actual electric current. In point of fact, such streams are deflected by means of magnetic flux just as movable conductors carrying electric currents would be deflected.

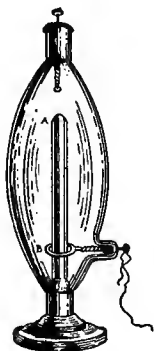


FIG. 68—
DEFLECTION OF
CHARGES BY
MAGNETIC FLUX

Suppose, for example, a soft iron rod, A, covered with an insulating material, Fig. 68, is sealed air-tight in a glass vessel containing a high vacuum. A metallic ring B is placed as shown so as to surround the iron rod at its lower edge without touching it. Now if the terminals of an electric machine or a Ruhmkorff coil are connected at the terminals of two platinum wires that are hermetically fused into the glass of the tube, a luminous sheaf of light will be seen pouring between the top of the iron rod A and the ring surrounding the iron. If, while this light is passing, the soft iron rod is strongly magnetised, the luminous sheaf will slowly rotate around the rod in a direction that depends on the direction in which the magnetic flux is passing in the electro-magnet.

While speaking in a previous chapter of diamagnetism, reference was made to Davy's experiment as to the action of magnetic flux on a carbon voltaic arc placed directly between the poles of a powerful electro-magnet. When no flux was passing the arc occupied an approximately vertical position between the upper and lower carbon rods. As

soon, however, as the flux was passed by sending an electric current through the magnetising coils of an electro-magnet, the flux caused the flame of the arc to be deflected in a surprising manner; for, instead of continuing as a vertical flame, it was at once driven out and caused to place itself at right angles to the direction of the magnetic flux, as would any diamagnetic substance. There were, therefore, in this experiment, two different forces at work. Carbon vapour is diamagnetic and was, therefore, placed in a position at right angles to the direction of the flux. But the charged, vapourised molecules of carbon contained powerful electric charges. Indeed, the entire arc was a powerful movable electric current, and was, therefore, moved by the magnetic flux, and, being moved, placed itself in a position in which the flux could pass through it with the least magnetic resistance; that is, in a position at right angles to the path of the flux.

When an electric discharge passes through a rarefied gas, so as to produce the well known luminous discharge, this discharge consists of molecules of the residual gases, being thrown off with great velocity as they pass between the poles. Now since these streams consist of electrified molecules of the residual gas and the still smaller metallic particles torn off from the metallic electrodes, and since, moreover, they move with great velocities, they possess the properties of an electric current and are, therefore, displaced or moved by the magnetic flux. In fact, in all cases where light is produced in the residual atmospheres of a high vacuum by means of electricity, the paths of the luminous streams can be changed in curious ways by causing magnetic flux to pass through them.

This fact makes it comparatively easy, in the case of certain discharges; *e. g.* X-rays, or Becquerel rays, that will be referred to in a subsequent chapter of this book, to tell whether they consist of streams of electrified particles, or are merely pulses or vibrations of the ether. If they consist of electrified particles they must necessarily be deflected by

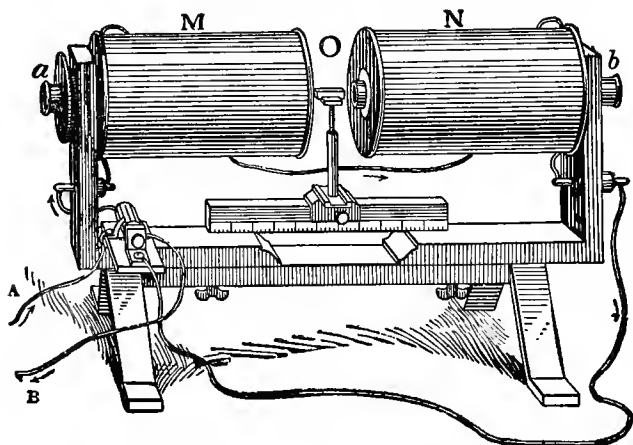


FIG. 69.—FARADAY'S MAGNETO-OPTIC APPARATUS

the approach of a magnet; whereas, if they consist of pulses of the universal ether, they are not necessarily so deflected.

Many strange effects are produced on the paths of luminous discharges in vacuum tubes by the passage of magnetic flux. This subject will be discussed at length in "The Wonder Book of Electricity."

There are, however, other instances of the effects produced on light by the passage of magnetic flux that we will discuss here. One of the most interesting of these was first

observed in 1845, by Faraday, who noticed that a beam of light, when in the condition known as polarised light, in which the vibrations of the ether take place in a single plane only, has, under certain conditions, its plane of polarisation shifted by the influence of magnetism.

The apparatus employed by Faraday for the purpose of showing this influence of magnetic flux on polarised light consisted of the powerful electro-magnet MN, of the shape and construction represented in Fig. 69. The soft iron cores of the electro-magnet were hollow, so as to permit the light to pass directly through them. A table for the support of a plate of peculiar transparent glass, O, was so placed that when the electric current was caused to pass through the electro-magnet, the magnetic flux was passed directly through the glass plate.

A full explanation of just what took place here would necessitate a knowledge on your part of how polarised light differs from ordinary light, and this is so difficult that I think it unwise to attempt an explanation of it. But it is sufficient to say that, when light is polarised, the vibrations in the ether causing the light take place in a single plane, while in ordinary light, the plane in which the vibrations occur is constantly changing. For this reason, polarised light possesses many properties that differ in a marked manner from ordinary light. For example, while a beam of ordinary light can pass through transparent substances in any direction, a beam of polarised light can pass through some of these substances in certain directions only.

Now in Faraday's experiment, the plate of glass was placed at O, so that not only the light from the candle

but also the flux from the electro-magnet MN could pass through the glass.

I must confess I am somewhat in a quandary as how best to explain to you what took place. There would be no difficulty whatever if you were familiar with the phenomenon of polarised light, which I am quite sure but few of you are. I must, therefore, content myself with saying that the hollow cores of the legs of the electro-magnet MN were not open at *a* and *b*, but were closed by optical devices that possess the power not only of permitting common light to pass through them, but also of polarising such light. If a candle flame were placed in front of *b*, its light could readily pass through *b*, and, provided no flux were passing between the poles of the electro-magnet, could also pass through the plate of heavy glass at O. Moreover, if the optical device at *a* were placed in a certain position the light could also pass through it, so that an eye at *a* could distinctly see the candle at *b*.

Now note what a curious effect was produced when magnetic flux was also permitted to pass through the plate of glass. The magnetic flux is invisible and therefore transparent. The plate of glass was also transparent as long as the magnetic flux was not passing. As soon, however, as it flows through the plate of glass, although neither you nor I could see any difference in the appearance of the glass, yet it has suddenly become opaque, for, to the eye placed at *a*, the candle flame disappears as completely as if it had been extinguished, or as if a sheet of black rubber had been placed in the gap between M and N. Here then is a remarkable instance in which magnetism has profoundly affected polarised light.

Without going into a detailed explanation, it is enough to say that what has actually happened is that the flux, while passing through the plate of transparent glass, has altered its optical structure. When the light from the candle flame passed through the device at *b*, it was polarised. An optical change in the glass, caused by the flux passing through it, has been such as to enable the glass to twist, turn, or rotate the plane in which the light has been polarised by *b*, so that when it reaches the optical device at *a*, it can no longer pass through *a*, unless it is turned to such an extent as to compensate or make up for the amount of the turning that has been caused by the plate of glass.

In 1877, this curious phenomenon was observed by Dr. Kerr of Glasgow: that a ray of polarised light when reflected or flung off from the polished surfaces of a magnet is rotated by the powerful magnetic whirls existing at the poles of a magnet. Now this is practically the same phenomenon that occurs in the light passing through a transparent substance; for, although a thick mass of iron appears to be absolutely opaque, yet a very thin slice of the iron will permit light to pass through it. Now the light that is reflected from the polished surface of a magnet actually penetrates the iron a very short distance before it is flung off, and although this distance is small, yet owing to the great density of the flux within the mass of iron of a powerful magnet, is nevertheless sufficient to twist or rotate the plane in which the light has been polarised.

Let me now give you a brief statement of the manner in which a theory known as the electro-magnetic theory of light was framed. It is interesting to note that this

theory had its origin in certain mathematical investigations, of great perplexity, that were begun in the year 1864, by a young, but exceedingly talented English mathematician, Clerk Maxwell. By means of these investigations, Maxwell, from an entirely theoretical standpoint, declared there could be no doubt that electro-magnetic waves could be set up in the universal ether, either by the rapid oscillations of an electric discharge, or by the rapid changes in the intensity of magnetism passing through a magnetic circuit, and that such waves would be found to possess all the properties of light.

Maxwell died while quite young, and was, therefore, unable to complete the details of his theory. His assumed electro-magnetic waves remained as theoretical waves only until Professor Hertz, of the University of Bonn, by means of investigations begun in the year 1882, was able before the close of the year 1888 not only actually to set up such waves, by spark discharges passing through an air gap between two polished metallic globes, but also to prove by a beautiful series of experiments that they possessed all the properties of ordinary light. He showed that they could be reflected, refracted, transmitted, polarised, etc., like ordinary light. For example, he showed that when the electro-magnetic waves produced in space by the discharge either of a Ruhmkorff coil or a Leyden jar, between two polished metallic balls separated by a small air space, were permitted to fall on various substances possessing reflecting powers, they would, like ordinary rays of light, be flung off or reflected from the surfaces at an angle equal and opposite to that of the angle at which they fell on the surface. He showed that when

the waves fell on substances that were transparent to them they underwent a change in direction at the bounding surface between the medium through which they had been passing and the new medium on which they had fallen, and they would turn them out of their original direction in accordance with what is known as refraction. He, therefore, constructed lenses by means of which he could bring these rays to a focus just as I do not doubt you have often done with rays of sunlight by means of a burning glass.

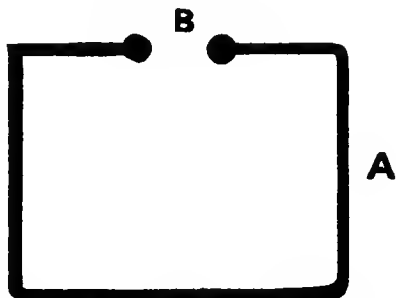


FIG. 70.—HERTZ'S ELECTRIC RESONATOR

He also constructed large prisms and so turned the rays out of their course that, since the rays consisted of a number of different wave lengths, they were differently refracted. Each separate ray emerged from the prism in a separate path, thus producing a spectrum of electro-magnetic light.

Hertz got the best results by the use of sparks produced by the discharges of Leyden jars, and found that waves so produced were more satisfactory than those obtained by the use of the Ruhmkorff coils. This was, probably, because the oscillations produced by the discharge of a

Leyden jar change their direction much more rapidly and, therefore, produce shorter wave lengths than those produced by the discharge of the Ruhmkorff coil.

It will be impossible here to do more than give a brief explanation of the means employed by Hertz to make these waves, which he called electro-magnetic waves, visible to the eye; for, although as has been proved, they possess all the properties of ordinary light, yet they are too long, or follow one another too slowly, to permit them to affect the human eye as ordinary light. Hertz was, therefore, obliged to provide a device, sometimes called the electro-magnetic eye, for detecting their presence. This device, as shown in Fig. 70, consists of an open circuited conductor A, generally rectangular in shape, as shown, with an air gap left at the middle, B, of one of its sides. The ends of the circuit at this gap were provided with small polished brass balls. The length of the open rectangular wire is such that the electro-magnetic waves passing through it were able to flow once through the circuit in exactly the same time as would the electro-magnetic waves passing through space in its neighbourhood. In other words, if this circuit, generally called by Hertz an electric resonator, and also known often as the electro-magnetic eye, is of such dimensions that it was tuned or in sympathy with the electro-magnetic waves in its neighbourhood, sparks would be seen between the polished balls at B. But if the waves in the neighbourhood were not in sympathy or accord with the resonator no sparks would be seen.

There is a simple experiment with sound waves that will probably help you in understanding what is meant by sympathetic vibrations. You can try this experiment with a

piano. Raise the lid at the top of the piano, so as to see the strings; place a foot on the loud pedal, bring your mouth near the opening, and, in a strong tone, sing any single note into the piano and then listen. You will hear this note thrown back by the piano.

Now sing another note in the same way. This note will also be flung back; and so, too, if you sound as many different notes as you may be able to sing. The explanation is simple when you once know it. There are a great number of strings in a piano, each of which is capable of producing a single definite note. One note differs from another because one string differs from another, principally because one string is of different length or is stretched more or less tightly than another; or because it consists either of a simple wire, or of a wire wrapped with another wire. It swings to-and-fro, or makes what is called a vibration, with a rapidity varying according to the above named circumstances, and this results in the same string always producing the same tone.

The placing of the foot on the loud pedal simply removes a damper from the strings, thus permitting all of them to vibrate freely. The note you sing into the piano has a definite pitch because something in the vocal organs of your throat, corresponding to a piano string, has been purposely stretched by you when you have made up your mind you are going to sing a certain note.

Since sound waves consist of to-and-fro motions of the air, when the waves fall on the strings of the piano they give them all a slight push or to-and-fro movements. Very shortly afterwards, however, the air particles again give the string another push and again move away from

them, and this continues a number of times, dependent on the pitch of the note. In some cases, for example, they move to-and-fro at the rate of 256 times a second.

Now consider carefully what will happen in the case of the particular string that is able to move to-and-fro exactly 256 times a second, or, in other words, of that string which is exactly in tune or in sympathy with the note you sing into the piano. The waves or to-and-fro motions of the air that produce this note strike the string and give it a little push or shove away from them. The string moves a short distance in this direction and then moves back towards the approaching sound waves. Since the rapidity of this to-and-fro motion is exactly the same as that of the sound waves you sang into the piano, at the moment the string has swung as far in this direction as it can and is just beginning to move back again, it gets another slight push from the sound waves, and this continues for 256 times in every second. By the end of a second, therefore, although each sound wave may have given the string a slight push, yet, having received 256 of these pushes, it will have acquired a perceptible motion.

Not so, however, with the other strings, whose rates of to-and-fro motions are not exactly 256 per second. Although at the first these strings are pushed away by sound waves practically as much as the particular string, still, moving as they are, to-and-fro at a different rate, they will not receive these faint pushes or impulses in the most favourable directions; for sometimes they are pushed away from the sound waves when they are moving in the opposite direction towards them, so that this push or impulse instead of adding its motion to the moving string

actually takes away some of the motion it already possesses. One string, and one string only, will be set into motion sufficiently great to affect the ear, and that is the string whose rate of vibration is exactly that of the note sung into the piano.

In a similar way the electro-magnetic waves that may be passing through space in the neighbourhood of an electro-magnetic resonator can set up sympathetic vibrations only in such a resonator that is tuned exactly to their rate of motion.

The principle of a tuned resonator is the principle on which the receiver of a wireless telegraph operates. In wireless telegraphy electro-magnetic waves are produced in various ways, as by the discharge of the Leyden jars or induction coils from the top of a mast reaching some distance above the surface of the earth. These waves move outward in all directions, with a velocity equal to that of light. Whenever they pass in the neighbourhood of a tuned circuit they will set up surgings in that circuit that are caused in various ways to affect delicate instruments, so that if the waves follow one another in a definite order, as for example in the order of the characters of the Morse telegraphic alphabet, despatches can be sent across the Atlantic Ocean from America to Europe, or even further. I will tell you no more about wireless telegraphy here since this will be fully discussed in "The Wonder Book of Electricity."

I have already told you not to suppose that electro-magnetic waves affect all substances just as ordinary light waves do. It is true that substances behave towards electro-magnetic waves as light does, so as to readily pass

through them ; or, in other words, the substances are transparent to the waves. But on account of the greater length of the electro-magnetic waves, they can readily pass through substances that are absolutely opaque to ordinary light. For example, in some of his experiments, as I have already mentioned, Hertz made lenses and prisms of substances transparent to electro-magnetic waves. I am sure you will be surprised when I tell you that some of these lenses and prisms were made of pitch, which, as you know, is quite black and absolutely opaque to ordinary light. Nevertheless, the pitch lenses or prisms were as transparent to the electro-magnetic waves, if, indeed, not more so, as pure glass or pure water is to light.

One of the most remarkable facts that has been discovered respecting electro-magnetic waves, is the fact that they travel through free space with a velocity that is exactly the same as that of ordinary light.

As I have explained, it is by electro-magnetic waves that wireless telegraphic despatches can be sent from station to station, although at distances of many thousands of miles. Professor Henry, already referred to for his investigation in electro-magnets, came very near discovering this kind of telegraphy.

Speaking of some experiments he was making with the discharges of Leyden jars, Henry said :

“ In extending the researches relative to this part of the investigations, a remarkable result was obtained in regard to the distance at which induction effects are produced by a very small quantity of electricity ; a single spark from the prime conductor of a machine, of about an inch long, thrown on to the end of a circuit of wire in an

upper room, produced an induction sufficiently powerful to magnetise needles in a parallel circuit of iron placed in the cellar beneath, at a perpendicular distance of 30 feet, with two floors and ceilings, each 14 inches thick, intervening. The author is disposed to adopt the hypothesis of an electrical *plenum* " (in other words, of an ether), " and from the foregoing experiment it would appear that a single spark is sufficient to disturb perceptibly the electricity of space throughout at least a cube of 400,000 feet of capacity; and when it is considered that the magnetism of the needle is the result of the difference of two actions, it may be further inferred that the diffusion of motion in this case is almost comparable with that of a spark from a flint and steel in the case of light."

I have endeavoured in this way to show you the manner in which the magnificent theory of light has been built up by the mathematical researches of Clerk Maxwell. It certainly shows that this young physicist possessed mental power of a very unusual character. Listen to the splendid eulogy pronounced by Sir Oliver Lodge at a lecture he gave in England a year after Maxwell's death:

"On November 5 last year there died at Cambridge a man in the full vigour of his faculties—such faculties as do not appear many times in a century—whose chief work has been the establishment of this very fact, the discovery of the link connecting light and electricity; and the proof—for I believe it amounts to a proof—that they are different manifestations of one and the same class of phenomena: that light is, in fact, an electro-magnetic disturbance. The premature death of James Clerk Maxwell is a loss to science which appears at present utterly irreparable,

for he was engaged in researches that no other man can hope as yet adequately to grasp and follow out; but fortunately death did not occur till he had published his book on "Electricity and Magnetism," one of those immortal productions which exalt one's idea of the mind of man, and which has been mentioned by competent critics in the same breath as the *Principia* itself.

"But it is not perfect like the *Principia*; much of it is rough hewn, and requires to be thoroughly worked out. It contains numerous misprints and errata, and part of the second volume is so difficult as to be almost unintelligible. Some, in fact, consist of notes written for private use, and not prepared for publication. It seems next to impossible now to mature a work silently for twenty or thirty years, as was done by Newton two and a half centuries ago. But a second edition was preparing, and much might have been improved in form if life had been spared to the illustrious author. . . .

"The main proof of the electro-magnetic theory of light is this. The rate at which light travels has been measured many times, and is pretty well known. The rate at which an electro-magnetic wave disturbance would travel, if such could be generated, can also be determined by calculation from electrical measurements. The two velocities agree exactly. This is the great physical constant known as the ratio ' v ,' which so many physicists have been measuring, and are likely to be measuring for some time to come."

CHAPTER XXVI

HAVE MAGNETS HEALING POWERS?

I BELIEVE it has always been found that charlatans and quacks, and, indeed, at times, fairly reputable physicians, are apt to claim that every mysterious or not yet thoroughly understood force possesses wonderful curative powers.

It is scarcely necessary to tell you that electricity is especially a force that has again and again been thus claimed as capable of curing all the ills flesh is heir to. Now it must be confessed that in electricity we find a force that is capable of doing much to cure diseased conditions of the human body, as well as to maintain and ensure its health and vigour. In the hands of skilled physicians, electricity can work wonders, but in the hands of quacks and charlatans it is perhaps more apt to do harm than good. Nor, in such cases, do certificates of wonderful cures count for much, since the patients who are killed give no certificates. It is only the people who are cured who testify to its curative powers, and these are probably far from being in the majority.

Wonderful curative powers have also been claimed for magnetism. I am not at all surprised at this, since the mystery surrounding this force has naturally led the ignorant to claim all kinds of impossible things for it. Indeed, there has arisen, although, I am glad to say, to but a slight extent, a variety of medical treatment known as

Magneto-Therapy. I shall show you in this chapter that magnetism is incapable of producing any effects whatever on the health of the human body.

It has for many years been believed by some that magnetism possesses the power of curing human diseases. I remember some time ago reading in an old English patent specification a description of a device for ensuring a prolonged healthy life. This so-called invention consisted in a bed that as far as I could see differed from other beds in no respect save that it was placed with its head and foot-board in a due north and south position, the inventor gravely informing all who used the bed that in order to secure its advantages they must be careful to sleep with the head to the north and the feet to the south.

Just what idea the inventor had, if, indeed, he had any, I do not know. Probably he had a vague notion that there was some wonderful potency about the north pole of a magnet, and, therefore, advised all who used his bed to sleep with their heads to the north and their feet to the south. Since, however, neither the inventor nor the users of the patent bed knew that the north magnetic pole of the earth is situated in its Southern Hemisphere, those who obeyed his directions had been sleeping all this time with their feet and not their heads to the north. They, therefore, had been happily ignorant of the fact that the invention was working exactly opposite to the way in which it was supposed to act. Happily, however, no harm was done; for we are certain that magnets possess no power whatever over the human body.

I also remember reading about another patented bed that also depended for its operation on the passage of mag-

netic flux through the body. Here, evidently with a view of preventing the magnetism escaping from the bed, the inventor had rested the bed posts on heavy glass balls that were to act as insulators. Now, since, as we have seen, magnetic flux can pass through glass almost as well as it can through air, the absurdity of such an invention is evident.

Still another inventor went even further in this ridiculous idea; for he wound huge spirals of insulated wire around his bed in such a manner that the sleeping person would be inside the helix. He then insured the passage of flux through the sleeper by causing electric currents to flow through the helix as long as the person was in the bed. Now if it could be shown that the passage of magnetic flux through the body is absolutely able to produce any beneficial effect whatever on its condition of health there might have been some sense in this invention. But since, as I will show you beyond the slightest possibility of doubt, magnetic flux produces no effect whatever on the health, its absurdity becomes self-evident.

Many years ago, Mr. Thomas Edison made the following interesting experiment in his laboratory. Wishing to see what, if any, influence is produced by the passage of strong magnetic flux through the brain, he kept a boy for a long time inside a huge electro-magnet with his head placed between the poles, so that the flux passed directly through his brain. If now a magnet is capable of producing any effect whatever on the body, it should certainly have done it in this case. But, as far as could be seen, no effect whatever was felt by the boy. When asked privately how he felt he replied confidentially: "The experiment is

bully. I am all right in the magnet. I like to be here, for I do not have to work while the experiment is going on and I can take a nap occasionally. But don't tell Mr. Edison. I hope he will keep me here for a long time."

You will remember that, while telling of the huge gun electro-magnet that had been constructed at the United States torpedo station at Willets Point, Long Island Sound, I described an experiment in which magnetic flux was passed through the body of a man from the back to the front. This flux was of a strength sufficient to rigidly hold heavy iron spikes both against the breast and forehead. Now since in these experiments no ill results whatever were produced in the man's health, it can be positively asserted that magnetic flux possesses absolutely no effects on the human body, and that Magneto-Therapy has no foundation in fact, and must, therefore, be regarded as a delusion.

Many of you have probably heard of the magnetised iron ring that is often worn on one of the fingers of the hand as a cure for rheumatism. It certainly seems impossible that such a ring can possess any curative powers. In the first place, the magnetic flux the ring produces is ridiculously small. In the second place, even if it were large, it could hardly affect the body. It is indeed strange that such an unlikely portion of the body as one of its fingers should have been selected as the preferable place for the application of magnetism as a curative agent. Even when applied in the shape of a magnetic belt worn around the body no effect can be produced, since the strength of the magnetism so produced is also ridiculously small.

The ancients entertained ideas of the curative powers of magnets that were equally ridiculous. Gilbert in his great book, "De Magnete, or the Lodestone," says that Dioscorides believed that if a piece of lodestone is finely ground, mixed with water, and swallowed in doses of about half a grain, certain disordered conditions of the blood will be greatly aided. He acknowledges, however, that, according to others, it is exceedingly dangerous to take magnetic medicine of this character even in small doses, since it may produce a melancholic condition of the mind and even death. The discordant views concerning the effects of lodestone as a medicine are reconciled by others by the fact that there are many different kinds of lodestones, some of which are beneficial and others highly dangerous. For example, it has been claimed that some varieties of lodestones produce a purgative effect not unlike castor-oil, while others produce entirely opposite effects.

It is claimed by still others that small quantities of ground lodestone when taken internally have the effect of preserving youthfulness and thus prolonging life.

Perhaps one of the most curious things about the lodestone medicine taken internally is the power it was believed to possess of drawing iron arrow heads from the body. Here a strange confusion of ideas existed as to the well known attractive power of the solid lodestone for soft iron, and its assumed power when taken internally of causing the arrow head to be silently absorbed. Indeed, Gilbert claims that Paracelsus, one of the earliest of the medical quacks, who nevertheless did much to forward the study of medicine, concocted one of his most famous salves or ointments for stab wounds made by iron daggers,

swords, etc., by mixing large quantities of powdered lode-stone in an ordinary ointment.

But it was in the case of a peculiar disease known as hysteria that magnetic treatment was claimed to produce the best results. In his "Philosophy of Magic," as translated by Thompson, Salverte makes the following statement concerning cures which it was claimed could be effected by what was called "The Royal Touch." Salverte is speaking about a well known quack named Greatracks, who cured his patients without the use of any medicine by the mere stroke of his hand.

"A more impudent quack than Greatracks has seldom appeared; he flourished in the seventeenth century. The belief in his power was general; from the most highly born and educated, to the most abject and illiterate mendicant, all sacrificed at the altar of Credulity, and relied on the healing touch of Greatracks. In a letter to Lord Conway, who sent for him from Ireland on account of the health of Lady Conway, this prince of impostors thus expresses himself: 'The virtuosi have been daily with me since I writ to your honour last, and have given me large and full testimonials, and God has been pleased to do wonderful things in their sight, so that they are my hearty and good friends, and has stopped the mouth of the Court, where the sober party are now most of them believers, and my champions. The King's doctors this day (for the confirmation of their Majesties' belief) sent three out of the hospital to me, who came on crutches; but, blessed be God! they all went home well, to the admiration of all people, as well as the doctors. Sir Heneage Finch says that I have made the greatest faction and distraction be-

tween clergy and laymen that any one has these thousand years.' Such was his boast; there is retribution in this world as well as in the next: the reputation of Greatracks soon afterwards declined as suddenly as it had risen."

Another effect that it was claimed could be produced by magnetism was the so-called "magnetic sleep." In such cases it was only necessary to impress on the imagination of the patient the fact that certain magic ceremonies would beyond doubt produce what was known as the magnetic sleep, a condition of half-consciousness, during which it was claimed wonderful results could be produced.

The alleged marvellous powers of the magnetic sleep and its miraculous effects were first pointed out in 1763, by Swedenborg, who claimed that by its use a man "may be raised to the celestial light even in this world, if the bodily senses could be entombed in a lethargic slumber."

Probably one of the most noted cases of belief in the curative power of magnetism was in what was known as the odylic or odic force, a variety of animal magnetism. This force was first described by Baron von Reichenbach, who claimed that he had discovered an entirely new imponderable force, produced mainly by magnets, that existed throughout all portions of the universe and differed essentially from any other known force.

The only manner in which the action of the odylic force, invisible, like magnetic flux, could be seen, was through the curious effects Reichenbach claimed it produced. It did not, however, affect all people alike, and could produce its mysterious effects on certain sensitive or hysterical persons only. You can understand, therefore, how such people could bring themselves honestly to believe they saw many

wonderful people and things that Reichenbach assured them were produced by the odyllic force. Some claimed that they could distinctly see faintly luminous emanations from the poles of a magnet. Others claimed that when the poles of magnets were drawn or slowly moved over different parts of their bodies they could distinctly feel the sensations of heat or of cold.

Naturally, since only a small and therefore, as they believed, highly gifted class of sensitives were affected by the odyllic force, a rivalry was set up between them, each one claiming to be able to see more than any of the others. Since none of them saw anything save only by the eye of the mind, you can understand how these women (they were most of them women) exaggerated or "batted them out"; for, as soon as one was ready to claim that she could see a little more than any of the others, there was always somebody ready to go her one better if, indeed, not several better.

In this way highly sensitive or hysterical patients claimed they could see faintly luminous flames issuing from the magnet poles. These flames were said to vary both in brightness and colour. Moreover, similar flames, it was claimed, could be seen distinctly issuing from the fingers of the person who was putting them under the influence of this peculiar force. They also claimed they could see flames of fire coming out of the ends of iron nails on the walls of a room on which pictures were hung.

You can understand how great a sensation was produced by Reichenbach's ridiculous claims. Intelligent physicians, however, studying the cures that were claimed

to have been obtained by the odyllic force, soon came to the correct conclusion that they were simply due to the influence of the mind over the body; that, if the patients were only made to believe they would see certain appearances, they would promptly see them, even whether what they were looking at was a natural magnet or simply a piece of wood painted to resemble a magnet.

Dr. Carpenter, in his "Mental Physiology," discusses the influence of the mind over the body as seen in so-called cases of influence by the odyllic force. In this connection, he quotes from a work entitled "The Power of the Mind over the Body" the following results that were obtained by a Mr. Braid:

"A lady, upwards of fifty-six years of age, in perfect health, and wide awake, having been taken into a dark closet and desired to look at the poles of the powerful horseshoe magnet of nine elements and describe what she saw, declared, after looking a considerable time, that she saw nothing. However, after I told her to look attentively, and she would see fire come out of it, she speedily saw sparks, and presently it seemed to her to burst forth, as she had witnessed an artificial representation of the volcano of Mount Vesuvius at some public gardens. Without her knowledge, I closed down the lid of the trunk which contained the magnet, *but still the same appearances were described as visible*. By putting leading questions and asking her to describe what she saw from *another* part of the closet (where there was nothing but bare walls), she went on describing various shades of most brilliant coruscations and flame, according to the leading questions I had put for the purpose of chang-

ing the fundamental ideas. On repeating the experiments, similar results were repeatedly realised by this patient. On taking this lady into the said closet after the magnet had been removed to another part of the house, she still perceived the same visible appearances of light and flames when there was nothing but the bare walls to produce them; and, two weeks after the magnet was removed, when she went into the closet by herself, the mere association of ideas was sufficient to cause her to realise a visible representation of the same light and flames. Indeed such had been the case with her on entering the closet, ever since the few first times she saw the light and flames. In like manner, when she was made to touch the poles of the magnet when wide awake, no manifestations of attraction took place between her hand and the magnet; but the moment the idea was suggested that she would be held fast by its powerful attraction, so that she would be utterly unable to separate her hands from it, such result was realised; and on separating it by the suggestion of a new idea, and causing her to touch the *other* pole in like manner, predicting that *it* would *exert no attractive power* for the fingers or hand, such negative effects were at once manifested. I know this lady was incapable of trying to deceive myself or others present; but she was self-deceived and spell-bound by the predominance of a preconceived idea, and was not less surprised at the varying powers of the instrument than others who witnessed the results."

Another case, also taken from Carpenter's "Mental Physiology," gives some experiments made on a man. This was also a patient of Mr. Braid and has been quoted from the book before referred to:

“I first operated on his right hand, by drawing a powerful horseshoe magnet over the hand, without contact, whilst the armature was attached. He immediately observed a sensation of cold follow the course of the magnet. I reversed the passes, and he felt it *less cold*, but he felt no attraction between his hand and the magnet. I then removed the cross-bar, and tried the effect with both poles alternately, but still there was no change in the effect, and decidedly no proof of attraction between his hand and the magnet. . . . In the afternoon of the same day I desired him to look aside and hold his hat between his eyes and his hand, and observed the effects when I operated on him, whilst he could not see my proceedings. He very soon described a recurrence of the same sort of sensations as those he felt in the morning, but they speedily became more intense, and extended up the arm, producing rigidity of the member. In the course of two minutes this feeling attacked the other arm, and to some extent the whole body; and he was, moreover, seized with a fit of involuntary laughter, like that of hysteria, which continued for several minutes—in fact, until I put an end to the experiment. His first remark was, ‘Now this experiment clearly proves that there must be some intimate connection between animal magnetism and mesmerism; for, I was most strangely affected, and could not possibly resist laughing during the extraordinary sensations with which my whole body was seized as you drew the magnet over my hand and arm.’ I replied that I drew a very different conclusion from the experiment, as I had never used the magnet at all, nor held it, nor anything else, near to him, and that the whole proved the truth of my position as to the extraordinary power of the Mind over the Body.”

That the so-called odylic force is merely the result of the wonderful power the mind is able to exert over the body, can be seen from the following quotations that are also either from Carpenter's "Mental Physiology," or are quoted by him from other books:

"If a fragment of anything, of any shape, be suspended from the end of the forefinger or thumb, and the attention be intently fixed upon it, regular oscillations will frequently be seen to take place. If changes of various kinds are made in the conditions of the experiment, corresponding changes in the direction of the movements will very commonly follow. . . .

"The public mind was directed to these facts, about the year 1850, by Dr. Herbert Mayo, who, having brought himself to accept Baron Reichenbach's 'Odyle' as a 'new force in Nature,' accepted these oscillations as a manifestation of it, and gave to this suspended body the designation of 'odometer.' After varying his experiments in a great variety of modes, Dr. Mayo came to the conclusion that the direction and extent of the oscillations were capable of being altered, either by a change in the nature of the substances placed beneath the odometer, or by the contact of the hand of a person of the opposite sex, or even of the experimenter's other hand, with that from which the odometer was suspended, or by various other changes of the like nature. And he gradually reduced his results to a series of definite Laws, to which he seems to have imagined them to be as amenable as are the motions of the heavenly bodies to the law of Gravitation.—('The Truths Contained in Popular Superstitions,' 3rd edition, 1851, Letter XII.)

“Other observers, however, who were induced by Dr. Mayo’s earlier experiments to take up the subject, and who worked it out with like perseverance and good faith, framed a very different code; so that it at once became apparent to those who knew the influence which ‘expectant attention’ exerts in determining involuntary muscular movements, that this was only another case of the same kind, and that the cause of the change of direction in each case lay in the Idea that some such change would result from a certain variation in the conditions of the experiment. Hence the general conclusions which each experimenter works out for himself, so far from being entitled to rank as ‘laws of Odylic force,’ are merely expressions of what has been passing (though perhaps almost unconsciously to himself) *in his own mind*. . . . The truth of this *rationale* was proved by the results of a few very simple variations in the conditions of the experiment. When it was tried upon *new* subjects, who were entirely devoid of any expectant idea of their own, and who received no intimation, by word, sign, or look, of what was anticipated by others, the results were found to have no uniformity whatever. And even those who had previously been most successful in this line of performance *found all their success vanish, from the moment that they withdrew their eyes from the oscillating body, its movements thenceforth presenting no regularity whatever*. . . . Thus it became obvious that the definite direction which the oscillations previously possessed was due, not to any Magnetic, Electric, or Odylic force, of which the operator was the medium, but to the influence directly exercised by his Ideas over his muscles under the guidance of his visual sense.”

CHAPTER XXVII

THE TALKING NEWSPAPER

MANY wonderful things have been accomplished in science. Some of these are so far ahead of what has already been done that we are apt to think, when something unusually wonderful has been announced, that it certainly marks the limit of human ingenuity; that we cannot expect it ever to be equalled in wonder by any subsequent achievement. But again and again what the world has believed to be the limit has been entirely surpassed by some still greater wonder. Now I have told you about many marvellous things in magnetism, but I have kept, for nearly the end of this Wonder Book, something I think you will acknowledge is far more wonderful than anything you have yet heard.

When Edison announced to the world his wonderful invention of the phonograph, not in a theoretical condition, but in actual operation, almost every one agreed, when they heard the little cylinder covered with a sheet of indented tinfoil talk almost as well as you or I can talk, that this invention was certainly the *ne plus ultra* of human ingenuity; that in all probability nothing would ever be able even to equal it. The same belief was expressed on the announcement of the earlier invention of the speaking telephone, an invention quite as marvellous as the phonograph, although the presence of an actual living person at the other end of the line seemed, to some, to rob it somewhat of

its wonderful nature. But the wonder I have now to describe to you, the talking newspaper, consisting as it does of a combination of a telephone and a phonograph, far exceeds either of these great wonder-workers.

The talking newspaper was invented by a Danish engineer named Waldemar Poulson of Copenhagen. Since this wonderful instrument depends for its operation on the

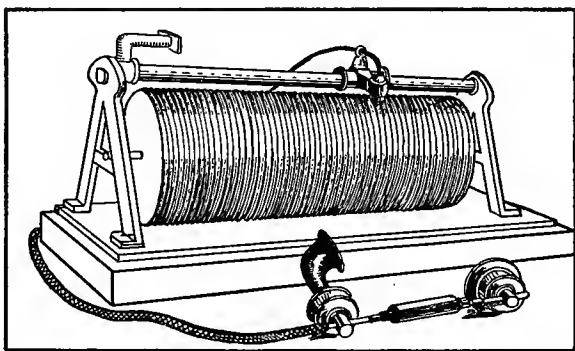


FIG. 71.—POULSON'S TALKING NEWSPAPER

magnetisation of a hardened steel piano wire, its description comes properly in "The Wonder Book of Magnetism."

Various names have been given to Poulson's talking newspaper. It has been called the micro-phonograph, the magnetic-phonograph, the tele-phonograph, and the telegraphophone. It is more generally called the micro-phonograph in America, but I think the name talking newspaper is one you can understand better, so that we shall therefore employ it.

The construction of the talking newspaper may be understood from an examination of Fig. 71. This apparatus

depends for its operation on the fact that when a steel piano wire is passed between the poles of a peculiarly shaped electro-magnet, called the recording electro-magnet, through whose coils various currents are passing, permanent magnetic effects are impressed on the wire. The magnetising coils of the recording magnet are placed in the circuit of an ordinary carbon telephone transmitter and a few cells of a voltaic battery. On speaking into the transmitter, variations in the resistance of the carbon contact points of the carbon transmitter are produced that cause corresponding variations in the strength of the

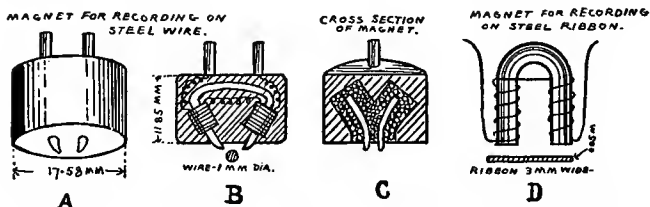


FIG. 72.—ELECTRO-MAGNETS EMPLOYED IN THE TALKING NEWS-PAPER

currents passing through the magnetising coils of the electro-magnet. These variations in the current strength magnetise the steel wire as it passes between the magnet poles and leave on it an invisible but permanent record of the variations in the magnetic intensity that are impressed on the record magnet by the sound waves that fall on the transmitting diaphragm.

The record wire employed in the apparatus shown in the above figure consists of a length of hardened steel piano wire having the diameter of about the twenty-fifth of an inch. This record wire is wound on the surface of a

cylinder as in Fig. 71. A small electro-magnet consisting of two separate electro-magnets, electrically connected, as shown at C, Fig 72, is placed so that its opposite poles embrace the wire as shown at B in the above figure. The cylinder, being revolved by an electric motor, causes the record magnet to move over entire length of the wire from right to left from one end of the cylinder to the other. The magnet poles, therefore, pass over the entire length of the record wire wound on the drum. There is then recorded on it whatever is said or sung into the telephone transmitter.

The drum or cylinder is rotated by any suitable means; such, for example, as an electric motor. By reason of this movement the entire length of the piano wire from right to left, that is, from one end of the drum or cylinder to the other, passes under the magnet.

I can imagine your asking what there is about such a device that would justify one in calling it a talking newspaper. As to the talking part, it *can* talk to you; and, as to the propriety of its being called a newspaper, I may tell you that it is capable of conveying intelligence of what has been going on in the world; is capable of circulating the news of the day; and of advertising certain articles or commodities offered for sale; that it does in general what the newspaper is intended to do, and can, therefore, very properly be called a newspaper.

The talking newspaper is certainly a wonderful improvement over the first German newspaper that was published in 1615, or the first English paper, that was published in London in 1622. It cannot only tell the news of the day, but can also speak it into the ear of the listener, who

can, therefore, become acquainted with what has been going on without even getting out of bed, or of turning on the light so that he can see to read.

I will now explain at greater length the manner in which the news is recorded on the piano wire. The magnetising coils of wire that are wrapped around the core of the electro-magnet B are connected, as shown, with the circuit of an ordinary carbon telephone transmitter. As I shall explain more fully in "The Wonder Book of Electricity," in this form of transmitter an electrical device known as the *induction coil* is employed, consisting of the usual primary and secondary windings placed close together. The primary winding of the transmitter is placed in the circuit of a small voltaic battery, while the secondary winding is placed in the coils of the electro-magnet B.

When one speaks into the telephone transmitter variations in the strength of the current passing through the primary coil are produced, by means of which corresponding variations are set up in the secondary coil. It is these variations that transmit to the telephone receiver the speech that has been uttered into the telephone, and thus permits it to be understood.

But the variations in the current so produced by speaking into the transmitter pass through the coils of the electro-magnet B, and, therefore, magnetise the hardened steel piano wire that is being drawn by the motion of the cylinder between its poles. In this way there is left in the steel wire a record of the variations in the magnetic intensity that have been impressed on the secondary circuit by the sound waves that have fallen on the diaphragm of the transmitting telephone.

The recording magnet is now placed at the beginning of the record on the wire with its invisible but permanent magnetic record of what has been spoken into the transmitter, and its coils are connected with the circuit of an ordinary Bell receiving telephone. The electric motor being set in action, the record wire is made to pass between the poles of the recording magnet. As the magnetised steel wire is drawn between these poles it acts as a magnet or series of magnets that are moved across the coils of wire wrapped on the poles of the recording magnet, and since, as the

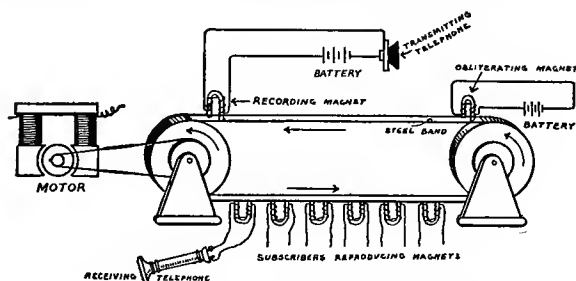


FIG. 73.—PLAN OF THE TALKING NEWSPAPER

record wire passes between these poles, it causes magnetic flux to alternately fill and empty the coils of wire on the record magnet, it acts as a dynamo-electric machine and produces currents corresponding exactly in strength, direction and order of sequence to the currents that pass through the magnetising coils of the recording magnet and thus leave their permanent but visible record on the wire. As these currents pass through the wire on the Bell receiving telephone they will reproduce in its diaphragm whatever has been spoken or sung into the transmitter.

Considerable difficulty was first experienced in obtain-

ing an electro-magnet sufficiently sensitive to record the speech that was spoken into the transmitting instrument. If wound in the ordinary manner, the electro-magnet was too slow in its action to give satisfactory results, but with the form of magnet shown at B, in Fig. 72, it is possible not only to transmit speech but even to be able to distinguish at the receiver the peculiarities of the voice so as to know who is speaking, provided, of course, one is familiar with this voice.

The manner in which this invention is applied to the talking newspaper may be understood from an examination of Fig. 73. Here an endless ribbon, or band of hardened steel, passing from one rotating cylinder to the other, is made to take the place of the magnetised piano wire. The direction of its rotation is indicated by the arrows. The means for keeping it in motion, in this case a belt passing over the pulley of an electric motor, is also shown. As the record ribbon is thus moved, a transmitting telephone, placed as shown at the upper part of the figure, impresses on the ribbon whatever news or speech is uttered into it. These impressions consist of north and south magnetic poles so varying in order and intensity as correctly to represent the directions of the rapidly varying electric currents passing through the coils of the electro-magnet B, in Fig. 72. The record on the steel band is made to reproduce the sounds uttered into the transmitting telephone, at any of the ten separate reproducing magnets placed as shown in the figure. Consequently, a subscriber may listen at any of these receivers. Any number of these reproducing magnets may be employed, even up to a thousand or more.

Of course, you will understand that the only apparatus placed in the house, room, or office of a subscriber is this receiving phone itself. All the other apparatus is placed in a central station, where the news is collected and transferred to the permanently magnetised steel ribbon.

CHAPTER XXVIII

MAGNETISM AND MAGIC

WHEN a boy sees anything the working of which he is unable exactly to understand he is apt to call it a magigger, or a majigger. I am uncertain as to the exact spelling of this word. While it is possible that it has been derived from "jigger," a general name given to a tool or appliance that during its working takes on irregular dancing movements, somewhat resembling the dance called a jig, the motions of which are so irregular as to fool or trick the observer, yet I believe the word is employed by boys rather in the sense of a magic-er. I have, therefore, spelled the word magigger.

It is possible that magigger is a new word for you. Indeed, I think you will look in vain for it, even in the largest dictionaries you can find; for it belongs to a class of words included under the general name of "slang."

Now, I would earnestly advise you to avoid the use of slang when it consists in the unauthorised popular use of a word of low or illiterate origin, but when, as is sometimes the case, it is merely an odd, grotesque or metaphorical expression that can only be regarded as slang because it has not yet acquired a reputable usage, I think its use can sometimes not only be tolerated but even encouraged. This, I think, is the case with magigger, a word that has been ingeniously coined by some brainy boy to explain a piece of apparatus capable of producing effects so strange and unexpected as to lead to the belief that they are due

to magic. Now, when you use a new word, you should be able to define it. I will therefore give you its definition: magigger, anything that magigs; that is, any device that produces effects so strange that they appear magical.

If you think a moment you will see that, while the word magigger permits of a wide usage, yet this usage necessarily becomes smaller as one's knowledge increases; for, as soon as the causes of any wonderful occurrence closely resembling magic are understood, all the magic instantly disappears.

It has often occurred to me that magnetism is capable of lending itself in a remarkable degree to the production of mechanical devices capable of being employed by the magician. Magnetic flux readily passes through a great variety of substances that are opaque to ordinary light. It would be easy, by suitably placing a magnet inside a wooden box in such a position that the magnet is capable of being moved in a certain direction on the approach of another magnet, to produce many curious effects. The magnetic flux passing through the board could, by moving the magnet, be readily made to give information to the magician that would enable him to do things that would seem inexplicable to all who are not in the secret.

Since the flux produced by an electro-magnet is in general much more powerful than the flux of permanent magnets, electro-magnets are, perhaps, more frequently employed by the magician. In this way numerous effects can be produced either by the to-and-fro movements of their armatures or, what amounts to the same thing, by the movements of an electro-magnetic motor. The advantages obtained by employing electro-magnets consist

not only in their greater strength, but also in the fact that the magnetism can be thrown on or off by the closing or opening of an electric current by a push button or a key placed at any distance from the device it is operating.

You all know how the pushing of a button that closes an electric circuit can ring an alarm bell at any distant point. Some time ago, when the knowledge of the practical applications of electro-magnetism was less common than now, a device, first exhibited by the great Houdin, was that known as the magic drum. Here a drum, suspended apparently by an ordinary cord midway between the ceiling of the auditorium and the platform, would unexpectedly begin beating a tattoo apparently, at times, for the purpose of preventing something the magician was trying to tell the audience or, at other times, in answer to certain questions addressed to the drum. It seemed almost weird that a drum hanging in a big auditorium, forty or fifty feet above the floor, should act as if it understood all that was being said. But the device was very simple. Inside the drum was an electro-magnet, arranged so that the to-and-fro movements of its armature, instead of striking a bell as in the case of the burglar alarm, struck the drumhead on the inside. What looked like an ordinary thread that was employed for the suspension of the drum contained two insulated wires by means of which the electric current was conducted to and from the coils of the electro-magnet. To start the drum it was only necessary to close an electric circuit, and this could readily be done by means of either a contact placed on the stage and operated by the foot of the magician, or by means of a key or push button operated by a confederate out of sight but not out of hearing.

In an improved form of magic drum two separate electro-magnets are provided; one for beating rolls or tattoos and the other for producing single raps. This latter electro-magnet is employed by the drum in answering questions in fortune-telling or in detective work. Of course much of the fun will depend on the cleverness of the operator in framing these questions.

If sometime, when you are in a large hotel, you will look at the annunciator board in a large frame hung on the wall back of the clerk's desk in sight of the bell-boys, you will hear every now and then a call bell ring which summons a bell-boy, and you will at the same time see somewhere on the face of the board a little shutter fall. In large hotels there are many hundreds of these shutters, numbered consecutively to, say, 900 or more, corresponding to the numbers of the different rooms. When a bell-boy has his attention called to the annunciator board by the ringing of the bell, he looks at the drop that has fallen and seeing on it a certain number, let us say 872, knows that someone in room No. 872, on the eighth floor, wishes some service, and of course goes up immediately.

Now what has happened is as follows: The guest in room 872, wishing a pitcher of ice water, one of the evening papers, or some other service, touches a push button, thereby closing a circuit through the coils of a small electro-magnet placed immediately back of shutter No. 872. The armature of this electro-magnet, being attracted to its poles, loosens the shutter and permits it to fall, thus displaying the number.

A similar device, or magigger, if my boy friends prefer the word, is very commonly employed by the magician,

who, on the touching of a push button, either by himself or by his confederate, permits a shutter to drop, disclosing to the great astonishment of the audience a ring or watch or a particular playing card hanging inside a glass frame.

In order to increase the mystery of this trick the pushing of the button by his assistant, or by the magician himself, is coincident with the firing of a pistol.

A magician's wand, though generally consisting simply of a suitably shaped stick of wood, is nevertheless often of no little assistance in the performance of tricks that require adroit sleight-of-hand; for, it gives the magician an opportunity for many movements that could not otherwise be made without awakening or attracting the attention of the audience to something the magician especially wishes should not be observed.

Often the magician's wand is more complex than it appears to be; for, it is provided at one end with a miniature pistol that may either fire a percussion cap only, or may even have means for igniting a small charge of powder. In some cases it also contains a small voltaic battery together with an induction coil arranged so that it is possible to give a fairly severe shock when incautiously handled by someone in the audience, and yet which can be safely handled by the magician, who knows its construction.

Here is another curious effect produced by electro-magnetism, an effect by the way that is astonishing even to the intelligent and learned. It consists of a closed box inside of which is suspended a very heavy wheel which has been set in rapid rotation by a concealed electric motor and battery, or in any other way. When a body, possessing

considerable weight, is rapidly rotating, a considerable force will be required to alter or change the plane in which it is rotating. When the box is handed to a person he finds no difficulty in carrying it in the direction of rotation, which, let us say, is along a due north and south line. If, however, he attempts to move it to the right or to the left, that is, to the east or to the west, a strange influence at once begins to oppose the carrying of the box in this direction. In this manner, intelligent people have been considerably surprised; but, as soon as the trick was explained to them, their astonishment of course ceased.

The great power with which electro-magnets attract their armatures or masses of soft iron to their poles is frequently utilised by magicians. A piece of soft iron is seen resting on a soft iron plate. A person called from the audience is asked to lift it, which he finds it easy to do. As soon, however, as the magician closes the circuit of the coils of an electro-magnet, the poles of which lie immediately under the plate of iron, the attraction is so great that it is impossible to raise it. This, as you will see, is a modern trick that we may regard as having been borrowed from the curious thing that happened to Magnes in Asia Minor, when he unexpectedly brought his crook in contact with a large piece of lodestone.

It will interest you if I quote from a book called "Modern Magic," by Professor Hoffmann, the role this trick played in Africa in the hands of the great Robert Houdin:

"The above trick is cited by Robert Houdin in illustration of the great difference which there may be, in point of effect, between the modes of presenting the same illusion. The reader may possibly be aware that Robert

Houdin was employed by the French Government, at one period of his career, in a mission to Algeria, with the object of destroying, if possible, the popular belief in the pretended miracles of the Marabouts, whereby these latter had obtained an extraordinary ascendancy over the minds of the ignorant Arabs. The plan adopted was to show, first, that a European could perform still greater marvels, and then to explain that these seeming mysteries were mere matters of science and dexterity, and wholly independent of supernatural assistance. The 'Light and Heavy Chest' was one of the prominent features of the programme, but if presented by that name it would have produced but very little effect. The fact that the chest became immovable at command would only have been attributed by the Arabs to some ingenious mechanical arrangement beyond their comprehension, but exciting only a momentary wonder. With great tact Robert Houdin contrived to turn the attention of his audience from the object to the subject of the trick, professing, not to make the chest light or heavy, but to make the person who volunteered weak or strong at his pleasure. Thus presented, the trick had the appearance no longer of a mere achievement of mechanical or scientific skill, but of a manifestation of supernatural power. We will tell the rest of the story as nearly as possible in Robert Houdin's own words, as related in the story of his life:

"'An Arab of middle stature, but well-knit, wiry, and muscular, the very type of an Arab Hercules, came forward, with plenty of self-confidence, and stood by my side.

"'Are you very strong,' I inquired, eyeing him from head to foot.

“ ‘Yes,’ he replied carelessly.

“ ‘Are you sure you will always remain so?’

“ ‘Perfectly.’

“ ‘You are mistaken; for in one moment I shall take away all your strength, and leave you as weak as a little child.’

“ The Arab smiled scornfully, in token of disbelief.

“ ‘Here,’ I said, ‘lift up this chest.’

“ The Arab stooped, lifted the chest, and said disdainfully, ‘Is that all?’

“ ‘Wait a bit,’ I replied. Then, with the solemnity appropriate to my assumed character, I made a gesture of command, and gravely said:

“ ‘You are weaker than a woman. Try *now* to lift that box.’

“ The strong man, perfectly indifferent about my magic spell, again catches hold of the box by the handle, and gives a vigorous pull to lift it; this time, however, the chest resists, and in spite of the most determined efforts, remains absolutely immovable.

“ The Arab wastes in vain over the unlucky chest an amount of force which would have lifted an enormous weight; till at last, exhausted, panting, and burning with shame, he ceases, looks dumbfounded, and begins to appreciate the power of the magic art. He has half a mind to give up the attempt; but to give up would be to acknowledge himself conquered, and to admit his weakness; and after having been famed for his muscular strength, to sink to the level of a child. The bare idea makes him furious. Gathering new strength from the encouragement which his friends offer him by word and look, he

casts towards them a glance which seems to say, 'You shall see what the son of the desert can do.' Once more he bends over the chest, his nervous hands grip the handle, and his legs, planted one on each side of the chest like two columns of bronze, serve as a fulcrum for the mighty effort which he is about to make. It seems almost impossible but that under such a strain the box must fly to pieces. Strange! this Hercules, a moment ago so strong and self-confident, now bends his head; his arms, riveted to the box, are drawn by a violent muscular contraction against his chest; his legs quiver, and he falls on his knees with a cry of agony.

"An electric shock, produced by an induction coil, had just been communicated, at a signal from me, from behind the scenes to the handles of the chest. Thence the contortions of the unlucky Arab. To prolong his agony would have been inhuman. I gave a second signal, and the electric current was cut off. My athletic friend, released from his terrible bondage, raised his hands above his head. 'Allah! Allah!' he cried, shaking with fright, then wrapping himself hastily in the folds of his burnous, as though to hide his disgrace, he rushed through the spectators, and made his way to the door of the hall."

I might add many additional magical feats that can be performed by the assistance of electro-magnets, such, for example, as spirit-rappings, in which the rappings are due to the movements of the armatures of an electro-magnet. I might also describe the construction and operation of a device known as the magic bell, as well as the crystal cash box. But the above must suffice.

It appears that magnetism was employed over half a cen-

tury ago as an aid in performing the so-called magical tricks. This will be seen from the following quotations taken from Hutton's "Researches in Science," published in 1851, and before referred to :

"For some years past, the properties of the magnet have been employed to perform several tricks, which excited a considerable degree of astonishment in those who first beheld them. No means indeed more secret, and at the same time more proper for action, could be employed than magnetism, since its influence is stopped by no body with which we are acquainted, except iron. This idea was first conceived by the celebrated Comus, who varied, in a singular manner, the different tricks performed by this agent, so that all Paris flocked, with the utmost eagerness, to the places where they were exhibited. He was admired by the ignorant, who considered him as a sorcerer, while the learned endeavoured to discover the artifice, which, however, was a profound secret as long as no one suspected magnetism to be the principal cause of it.

"We shall here endeavour to give an idea of some of these tricks, as they will form a fund of rational amusement to those who know how to perform them.

"Those who exhibit these tricks often employ a pretended magic telescope, by means of which one can see, it is said, through opaque bodies. It is nothing else than an instrument in the form of a telescope, at the bottom of which, that is towards the object glass, there is a magnetic needle, which assumes its proper direction when the telescope is placed upon the side which that object glass forms.

"To construct this telescope, provide a turned tube of ivory, wider towards the end where the object glass is

placed; but the ivory must be of sufficient thinness to admit the light through to the inside. The narrow end is furnished with an eye-glass which serves to show more distinctly the inside of it. The other end also is furnished with a glass which has the appearance only of an object glass, the posterior surface of it being opaque, so as to serve for the base or bottom of a sort of compass or magnetic needle which turns on a pivot fixed in its centre. When the telescope rests on the end containing the object glass, this needle assumes a horizontal position, and points towards the north, or towards a magnetic needle in the neighbourhood. It is necessary also to have a real telescope, similar in appearance to the other, in order that it may be shown instead of it, which may be done by dexterously substituting the one for the other.

“When you wish to employ the pretended magic telescope, place it with the object glass downwards upon anything you intend to examine, and if there be a magnet, or piece of magnetised iron below it, the needle will turn to that side.

“If you are desirous of employing the ten ciphers, take ten small squares, of an inch and a half on each side, and on the upper face of each make a groove; but let these grooves be in different directions; that is to say, the first intended for the number 1 must proceed directly from the top to the bottom; the second must deviate to the right, so as to form an angle equal to a tenth part of the circumference; the third an angle of two-tenths; and so of the rest, which will give ten different positions. Then introduce into these grooves small bars of steel, well magnetised, taking care to turn their north poles to the proper

direction; cover these grooves and the face of the squares with strong paper, in order to conceal the bars. You must also provide a narrow box, capable of containing in its breadth one of these squares, and of such length that they can all be arranged in it.

“Then desire a person in your absence to take several of these squares and arrange them in the box in any manner, at pleasure, so as to form any number whatever, and to shut the box; after which you are to tell the number which has been formed. Deposit your pretended telescope on the place of the first square, that is on the left, if the figure below it be unity; the needle will turn in such a manner that the north point or pole will be before you. If the figure be 4, it will turn to the fourth division of the circle, which is equally divided into ten parts; and so of the rest. It will thence be easy to discover the figure in each place, and consequently to tell it.

“A word written in secret, with given characters, may be discovered in the same manner; also an anagram, formed of a proposed word, as *Roma*, which gives *amor*, *mora*, *orma*, *maro*, etc.; or a question which has been selected from several persons, and put into the box. In short, this trick may be varied in a great many ways, exceedingly agreeable, but all depending on the same principle.

“The box of metals, for example, is only a similar variation of the same trick. You put six plates of different metals in a box, and bid a person take any one of them, and put it into another box, and shut it. You may then easily tell which one he has taken. These plates are of such a form that they can occupy in the small box only one position. Each of them, that of iron excepted, contains

in its thickness a magnetic bar, arranged in situations which are known, and these situations are discovered by means of the pretended magic telescope; consequently the nature of the metal must be known. No magnetic bar is placed in the plate of iron because this would be useless; but one side of the plate may be magnetised, or if it be not magnetised, the indeterminate direction of the needle will announce that it is iron."

CHAPTER XXIX

GILBERT'S "DE MAGNETE"

WHEN its early date of publication is considered, perhaps one of the most remarkable books that have ever been written on the subject of magnetism is the "De Magnete, or the Lodestone." Although its author, William Gilbert, was an Englishman, yet the book is written in the Latin language.

Gilbert was born in Colchester, in 1540. Without discussing his personal history, I will merely say that he was a practising physician, and had received the honourable appointment as physician to Queen Elizabeth of England. He was elected Fellow of the Royal College of Physicians in 1573, and continued a Fellow of the same college until the year 1600, when he was elected its President.

During his early life, Gilbert devoted himself to chemistry. After having obtained considerable knowledge of this subject he spent the remainder of his life in the study of magnetism.

It was the great interest Gilbert took in magnetism that led him to write "De Magnete." This is a famous work, and has properly been regarded as the most valuable book on magnetism that was ever published, not only before the year 1600, but also for many decades afterwards. Considering the early date of its publication, this book is remarkable by reason of the extended knowledge it shows that Gilbert had gained on the subject of magnetism. I have purposely left a brief description of this book to this

last chapter of "The Wonder Book of Magnetism" because you are now in a position to appreciate many of the facts of magnetism it describes. In my study of this book, I have employed an excellent translation into English by P. Fleury Motteley. The translation is well done and, therefore, makes an exceedingly interesting book, which I would advise you to read whenever the opportunity presents itself.

Like all scientific men, I have the highest regard for Gilbert's work; for, I find it shows, for this early date, a wonderful grasp of the science of magnetism. I regret to say, however, I cannot agree with the following statement of Dr. Whewell:

"Gilbert's work contains all the fundamental facts of the science, so fully examined, indeed, that even at this date we have little to add to them."

Now, in point of fact, Gilbert's book contains no reference whatever to such fundamental discoveries as the relations of magnetism to electricity as first discovered by Oersted, nor of the production of electricity by magnetism as discovered by Faraday, although it is true that Gilbert does trace with fair clearness, considering the time at which he wrote, some of the resemblances as well as some of the differences between electricity and magnetism. I agree, however, with Dr. Thomas Thomson's statement that the book, "De Magnete," is "one of the finest examples of inductive philosophy that have ever been presented to the world." This is the more remarkable because the "De Magnete" preceded Bacon's "Novum Organum," in which the methods of the inductive philosophy were publicly explained for the first time.

Poggendorff, the German physicist, had so high an opin-

ion of the ability of Gilbert that he called him "The Galileo of Magnetism."

It is a fitting tribute to the work accomplished by Gilbert that when scientific men adopted the plan of naming the practical electric and magnetic units after the world's great scientific men who have finished their labours on the earth, they selected the name of Gilbert as the name for the practical unit of magneto-motive-force. This is a far greater honour than you may think; for, in order to have one's name given to an electric or magnetic unit, one must have occupied a very prominent rank in some particular branch of science. You can see this when I mention some of the men whose names have been given to these units; they are Faraday, Oersted, Ampère, Coulomb, Ohm, Volta, all of whom unquestionably occupied the highest rank in their particular branch of science.

I believe I cannot close this Wonder Book on Magnetism in a better way than by calling your attention briefly to some of the many important facts concerning magnetism that are to be found in the "De Magnete."

In the first place Gilbert was the first to give the name "poles" to the ends of the magnetic needle. He called the pole that pointed to the earth's north magnetic pole the south pole of the needle, and that which pointed, approximately, to the earth's south pole, the north magnetic pole of the needle. This, of course, was before the time when men agreed to call the end of the needle that pointed approximately to the north pole of the earth the north pole of the needle, remembering of course that it is a south magnetic pole that exists in the earth's Northern Hemisphere.

Gilbert does not seem to have known that there were any other bodies than iron or the lodestone that possessed magnetic properties; for he called particular attention to the fact that all other substances that possessed magnetism to some degree owe their power to the presence of iron in some condition or other.

Perhaps the following quotation from JOHN ROBISON will give you an excellent idea of how Gilbert's "De Magnete" was regarded by scientific men in 1822:

"This work of Dr. Gilbert's relates chiefly to the lodestone, and what we call magnets; that is, pieces of steel which have acquired properties similar to those of the lodestone. But he extends the term magnetism and the epithet magnetic to all bodies which are affected by lodestones and magnets in a manner similar to that in which they affect each other. In the course of his investigations, indeed, he finds that these bodies are only such as contain iron in some state or other; and in proving this limitation he mentions a great variety of phenomena which have a considerable resemblance to those which he allows to be magnetical, namely, those which he called electrical, because they were produced in the same way that amber is made to attract and repel light bodies. He marks, with care, the distinctions between these and the characteristic phenomena of magnets. He seems to have known that all bodies may be made electrical, while ferruginous substances can be made magnetical. It is not saying too much of this work of Dr. Gilbert's to affirm that it contains almost everything that we know about magnetism. His unwearied diligence in searching every writing on the subject, and in getting information from navigators, and his incessant oc-

cupation in experiments, have left very few facts unknown to him. We meet with many things in the writings of posterior inquirers, some of them of high reputation and of the present day, which are published and received as notable discoveries, but are contained in the rich collection of Dr. Gilbert. We by no means ascribe all this to mean plagiarism, although we know traders in experimental knowledge who are not free from this charge. We ascribe it to the general indolence of mankind, who do not take the trouble of consulting originals, where things are mixed with others that they do not want, or treated in a way and with a painful minuteness which are no longer in fashion. We earnestly recommend it to the perusal of the curious reader. He will (besides the philosophy) find more facts in it than in the two large folios of Scarella."

I need hardly say that I must make the same objection to the above statement by Robison that I made to that of Whewell, although this statement is less objectionable since it only states that Gilbert's book contains *almost* everything we know about magnetism. But even this I am sure is quite inaccurate.

In his book, Gilbert refers very frequently to what he calls a *terella* or little earth. This consisted of a piece of lodestone cut or shaped into the form of a sphere and provided with two opposite poles situated approximately at the ends of its axis. He also frequently refers to a magnetised versorium, or a permanently magnetised bar or needle supported in a horizontal position on a vertical point, so as to be able to point or be moved under the influence of the earth's magnetism, or of the *terella*. His versorium was practically a compass needle.

In the first chapter of Book VI, on the globe of the earth as a lodestone, Gilbert calls attention to the fact that all the experiments that have been tried with the terella can be repeated on the earth itself; that a lodestone, placed so as to be free to move, is attracted by the opposite magnetic poles of the earth just as it is by the poles of a terella; that iron is endowed with polarity by being placed in contact with the earth in a direction extending between its two poles; that magnetism can be destroyed by heat; that a bar having thus lost its magnetism can be again endowed with this property by leaving it in contact with the earth. He also discovered that, if a bar of steel is heated to a red heat while in such a position that the earth's magnetism passed through it in the direction of its length, it will become permanently magnetised when cooled.

Reference is also made to the dip of the magnetic needle. Indeed, since Gilbert had so clearly recognised in his book the fact that the entire earth acted as one huge magnet, it is evident that he thoroughly understood the cause of the dip or inclination of the compass needle. He calls attention to the fact that when a bar of unmagnetised iron is accurately balanced on a vertical support so that it shall come to rest in a true horizontal position with each pole at the same distance from the earth's surface, that, as soon as it is magnetised, if free to move in a vertical plane, it will lose its horizontal position and will dip or incline towards the earth, and that the amount of this dip increases the nearer to the magnetic poles the needle has been carried. He probably obtained this knowledge of the dip of the needle from Norman.

Gilbert was too good a chemist not to know that the

lodestone is merely a peculiar form of iron ore, and that it acquired its magnetic properties by simply coming in contact with the magnetised earth.

He also appears to have recognised the advantages that we have already pointed out that are possessed by masses of soft iron called pole pieces, when closely attached to the surface of the lodestone. He calls attention to some experiments he made of a mass of lodestone that could only hold or support a piece of iron weighing four ounces, but was able to sustain a weight of twelve ounces when suitably provided with masses of soft iron. As you will remember, Jamin at a much later date employed the same device for strengthening the attractive power of his compound steel horseshoe magnet.

I might readily greatly extend the number of facts referred to in Gilbert's book, but I think the above will suffice to show the remarkable grasp its author had on magnetic science at this very early date.

Before closing I wish to express the hope that I have presented some of the simple effects of magnetism, and, indeed, I may say most of the effects of magnetism, in such a manner as will inspire you, after having read "The Wonder Book of Magnetism," to wish to know more about this curious force, and that you may, therefore, be induced to read more advanced books and thus extend the range of your knowledge. If I am successful in doing this, I shall not regret the labour of writing this book.

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